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TECHNOLOGIES TO SUSTAIN TROPICAL FOREST RESOURCES

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Foreword

The United States has a stake in the sustained economic development of tropical nations for humanitarian, political, and economic reasons. To a great extent, the development of these nations depends on increasing production from their potentially renewable soil, forest, and water resources. But tropical forest resources, which cover nearly one-half of the tropical nations' land, are being consumed at a rate that may make them nonrenewable. They are exploited for timber and cleared for pasture and cropland with little regard for their abilities to produce—in a long-term sustainable fashion—important goods, maintain soil productivity, regulate water regimes, or regenerate themselves. Much of the recent deforestation occurs where the new land uses cannot be sustained and it causes productivity losses that tropical nations and the world can ill afford.

International recognition of the importance of tropical forests, and efforts to sustain the productivity of these resources, have increased significantly in the last decade. In 1980, the House of Representatives Committee on Foreign Affairs, Subcommittee on International Organizations, held hearings on tropical deforestation. The committee then requested the Office of Technology Assessment (OTA) to conduct a more thorough assessment of the problem, the technologies that could help sustain tropical forest resources, and possible options for Congress. The Subcommittee on Insular Affairs of the House Committee on Interior and Insular Affairs and the Subcommittee on Environmental Pollution of the Senate Committee on Public Works endorsed the request. The Senate Committee on Energy and Natural Resources asked that the assessment specifically address forest resources of the U.S. insular territories in the Caribbean and western Pacific. The report and its two background papers *(Reforestation of Degraded Lands* and *U.S. and International Institutions)* identify and discuss in-depth some of the constraints and opportunities to develop and implement forest-sustaining technologies.

OTA greatly appreciates the contributions of the advisory panel and workshop participants assembled for the study, the authors of the commissioned technical papers, and the many others who assisted us, including liaisons from other Government agencies. As with all OTA studies, however, the content of the report is the sole responsibility of OTA.

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Introduction

Introduction

Each year, 11.3 million hectares of the Earth's remaining tropical forests (an area roughly the size of Pennsylvania) are cleared and converted to other land uses or to unproductive land. Where the land can support sustainable agriculture, deforestation may be beneficial. But most of the Tropics' remaining forest land cannot sustain continuous farming or grazing using current practices and so is soon abandoned. The abandoned land has lost much of its inherent productivity—a loss the tropical nations and the world can ill afford. The United States, however, can contribute expertise to develop and disseminate technologies that could reduce the need to convert forests to unsustainable land uses.

Forest land and former forest land in tropical areas can be classified as undisturbed forest, disturbed forest (secondary forest and manmade forest), converted land (cropland and grazing land), and unproductive land.* The products from these lands differ, with the most actively managed lands—cropland and manmade forest—generally yielding the highest economic value. Secondary forest is often perceived as relatively unproductive. Yet all forested land provides important services including climate and runoff regulation, water retention, and maintenance of an enormous, still-uncataloged stock of species.

Depending on the methods of management, these natural resources may be sustained or unsustained. Sustained resources are those in which the inherent productivity is not diminished over time. Conversely, unsustained resources suffer declining or degraded productivity. Productivity of almost any land can be sustained by applying substantial inputs (e.g., fertilizer, water), but this is not the general practice on tropical lands.

Undisturbed forest is the only productive form that maintains itself without human management. Four of the land types—cropland, grazing land, secondary forest, and manmade forest—potentially are interchangeable. For example, cropland can be fallowed into grazing land, which can be planted with trees. In some cases, several land uses can be realized simultaneously—e.g., agroforestry can combine agriculture, forestry, and grazing. Little, if any, land changes back into undisturbed forest or out of unproductive land, although in theory undisturbed forest might be regenerated from other land types or unproductive land might be made productive if given enough investment or time to recuperate (fig. 1).

Because this process moves tropical land from forest to unproductive land rapidly and from unproductive land back to forest more slowly, the area of unproductive land is growing steadily. Thus, serious land degradation is taking place, but the change may not be felt immediately in terms of price or availability of products. This is because the intermediate levels of land use are being maintained by continually clearing undisturbed forest to replace land that becomes unproductive. Figure 2 depicts the trend of land-use changes over time typical of tropical areas.*

***Undisturbed forest**—natural tropical forest with at most a few small areas cleared by natural or human-induced events, regenerating by natural stages of succession.

Disturbed forest—includes:

- *Secondary forest* or forested land that has been cleared in large areas within the last 60 years, commonly for crops or pasture. Usually it is sufficiently degraded or harvested so often that it does not return to its original state. Trees may be managed or left to natural succession, and
- *Manmade forest* planted and maintained in trees, often in exotic species, often a tree monoculture and sometimes also with a useful understory.

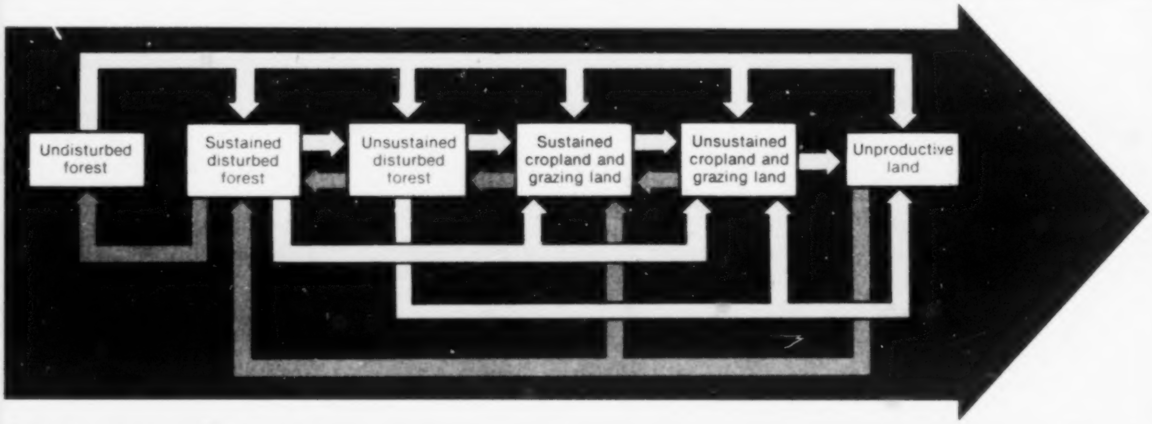
Converted Land—includes:

- *Cropland* planted annually or every few years with food or fiber crops, and
- *Grazing land* covered permanently with grasses, legumes, and/or herbaceous species, harvested by grazing animals.

Unproductive land—land that has been so degraded that it produces few useful products and provides minimal environmental services (e.g., erosion and flood control). It usually supports very little growth of useful species and does not return naturally to any of the previous categories.

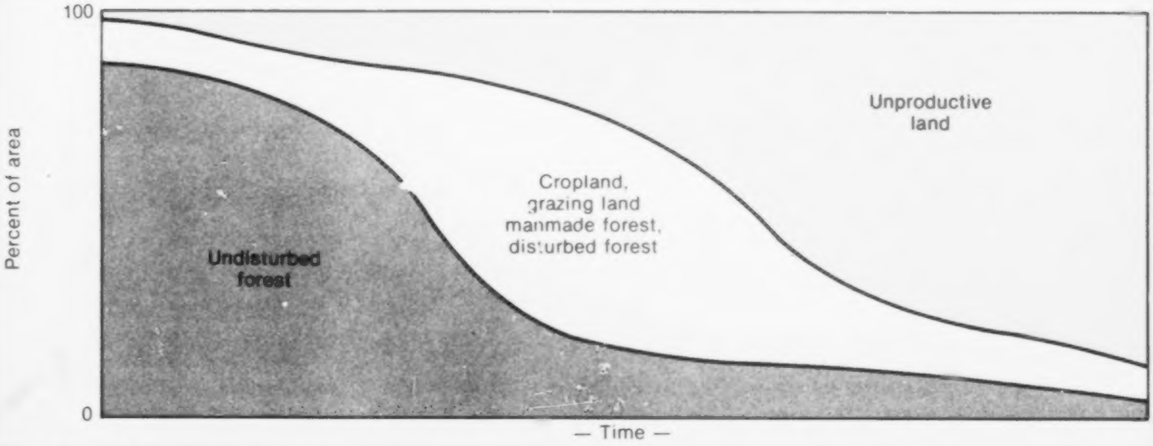
*This discussion does not present documented trends in land class but provides a general discussion of concepts. The interactions implied by the diagrams are derived from the principles and experience of members of the Advisory Panel and of a workshop attended by Dr. Donella Meadows, Dr. Jeff Gritzner, Dr. Frank Wadsworth, Dr. Jeff Romm, Dr. John Terborgh, and the OTA project staff. Thus, figures 2 and 3 present no scales, nor are specific countries or regions classified by position on the curves.

Figure 1.—Trend of Change Among Tropical Forest Land Uses


Undisturbed forest
Sustained disturbed forest
Unsustained disturbed forest
Sustained cropland and grazing land
Unsustained cropland and grazing land
Unproductive land

SOURCE: Office of Technology Assessment.

Figure 2.—Conceptual Diagram Indicating Land-Use Changes Typical of Tropical Asia



SOURCE: Office of Technology Assessment.

If nothing were done to change the system, the point at which the amount of undisturbed forest land and unproductive land stabilize for a given region would be, in theory, where the cost of clearing the next acre of undisturbed forest equals the cost of reclaiming an acre of unproductive land. Since that cost is high for known technologies, this equilibrium implies little accessible undisturbed forest, a great deal of unproductive land, and extremely low levels of production. The actual equilibrium may be delayed until even more undisturbed forest is cleared because costs and benefits accrue to different groups of people, skewing both motivations to invest and to exploit.

Many technologies exist but are not fully used to prevent conversion of productive land to unproductive land, to increase yields on intermediate lands, or to harvest from undisturbed forest without converting it to a less sustainable land type. There are also social changes both possible and desirable to reduce the driving forces behind conversion to unsustainable uses.

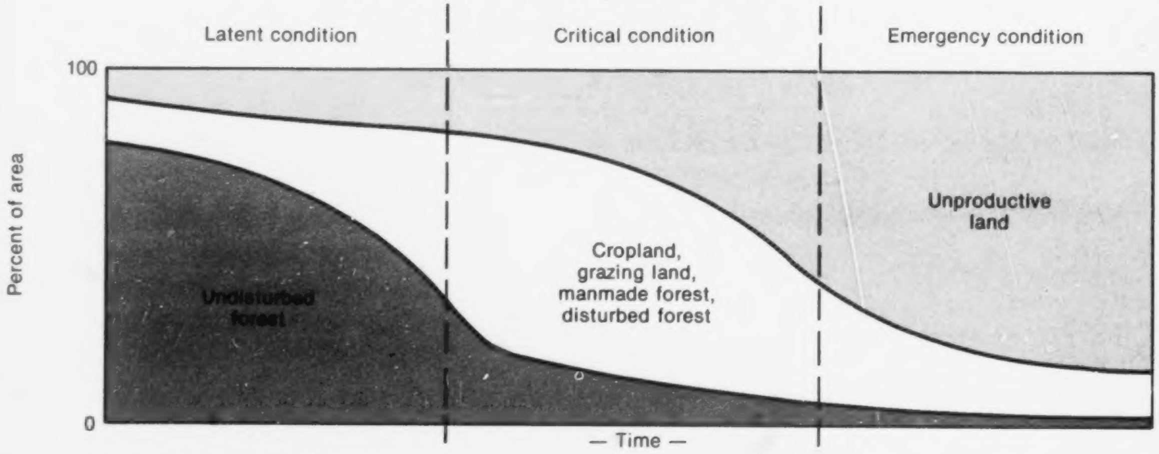
Because different countries or regions of countries fall at different points along the curves in figure 2, the actions needed to halt this degradation would be most effective if designed for the urgency of the situation in each country. For example, regions with low rainfall and/or dense populations probably follow this process more rapidly than countries with moist forest and large areas of currently inaccessible land. Categorization of countries or major regions to indicate the urgency for actions to address loss of tropical forest resources and degradation of land productivity might take the form indicated in figure 3:

- Countries where the problem is **latent but not compelling:** A considerable amount of original forest land remains, but without appropriate measures, population pressures and development needs can be expected eventually to propel these countries into the next categories.
- Countries where the problem is **critical:** Much original forest land has been converted into the four intermediate uses, including most of the land capable of sustaining continuous agriculture. Further clearing is occurring and technologies to sustain productivity on these lands generally are not applied.
- Countries where **emergency** measures are required—the ratio of unproductive land to original undisturbed forest is high and increasing, severe shortages of locally produced forest products are occurring, and the amount of intermediate land types is declining rapidly because technologies are not adequately used to sustain land productivity.

An improved division of countries into categories might account separately for urgency of human needs (e.g., food, fuelwood, materials for shelter, fodder, etc.) and urgency of ecological need (e.g., loss of genetic diversity). The Food and Agriculture Organization has categorized countries by need for action to ameliorate fuelwood deficiencies, but scales to measure other dimensions of forest resource value have not been created.

The loss of tropical forest resources is not new, and its effects are not restricted to those who live within the forests. Part I of this report describes the **Background** of tropical forest resource changes, including who is affected,

Figure 3.—Conceptual Diagram Indicating Possible Categorization of Countries or Regions by Urgency of Land Degradation Problems



SOURCE: Office of Technology Assessment.

the current status, the visible agents and underlying causes of change, and the organizations—United States, national, and international—involved. This section also describes the tropical lands of most direct concern to the U.S. Congress: the U.S. tropical territories.

Part II of this report, **Technology Assessment,** discusses various technologies for resource-sustaining development of tropical forest lands. The technologies considered cover a broad range. Some are techniques to manage the forests—undisturbed and disturbed—and some are technologies to use forests to protect related resources such as agriculture and water. Others are techniques to prepare people for the various tasks involved in sustaining tropical forest resources, such as resource development planning, education, research, and technology transfer.

Within each technology discussion, actions are suggested to promote development of sustainable tropical forest use. In general, actions can enhance the stability and productivity of tropical lands if they:

- reduce degradation of the resource base,
- reduce demand on the ecosystems,
- provide more timely and accurate information to decisionmakers or reduce the time necessary to implement decisions.

A final chapter in this section discusses application of the various kinds of technologies to the U.S. tropical forests.

Part III describes **Issues and Options for Congress** to promote development and use of technologies that can sustain tropical forest resources globally and within U.S. tropical territories. The organization of options for the Congress does not indicate the relative importance of the various measures. If long-term actions are not taken to build institutions concerned with the sustainable use of tropical forests, short-term actions will be overwhelmed. And conversely, if short-term measures are not taken, development of institutions to manage the forest resources in the long term may be pointless.

Chapter 1

Summary

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Chapter 1

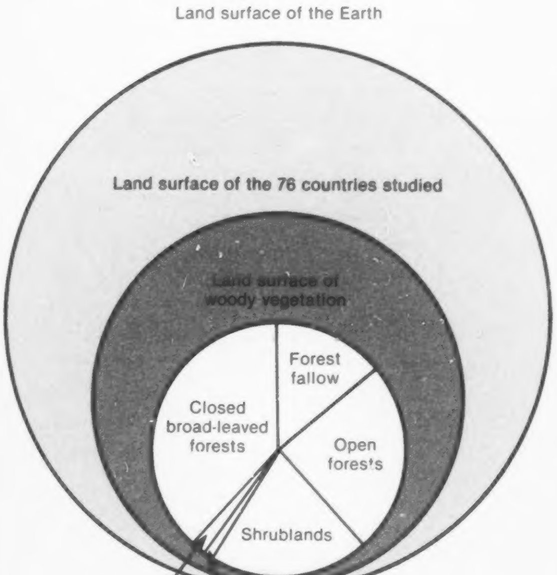
Summary

INTRODUCTION

Forests of various kinds cover 42 percent of the tropical nations' land (fig. 4). To support a population of 2 billion, these nations must use the natural resources found in these forests: soil, water, plants, and animals. The productivity of these resources can be renewable, but only if tropical people use resource-sustaining technologies.

Some tropical nations are experiencing severe shortages of forest products and services. To avoid even more acute problems, they need to restore resource productivity. Other nations, even those with adequate forests, need to sustain their forest resources to avoid future problems. In just 30 years, the population of tropical nations is expected to double to 4 billion people. Thus, the importance of tropical forest productivity is increasing as more and more people depend on forest products and services for basic needs such as fuel, materials for shelter, and a reliable water supply.

Figure 4.—Global Areas of Tropical Woody Vegetation


Land surface of the Earth
Land surface of the 76 countries studied
Land surface of woody vegetation
Forest fallow
Closed broad-leaved forests
Open forests
Shrublands
Conifer forests
Plantations

SOURCE: M. Hadley and J. P. Lanley, "Tropical Forest Ecosystems: Identifying Differences, Seeking Similarities," *Nature and Resources* UNESCO, 19(1):2-19, 1983.

Substantial institutional activity is occurring worldwide that directly or indirectly benefits tropical forest resources. The U.S. Agency for International Development (AID), the United Nations agencies, the multilateral development banks, and others have increased their attention to forestry in recent years. Private corporations and nonprofit organizations also have been involved in the search for solutions to tropical forest problems. Most importantly, tropical nations' governments have come to recognize that deforestation and forest resource degradation constrain their economies and their development options.

The large number of organizations that have some responsibilities in forestry might imply that an adequate level of activity is under way. But the total amount of expertise and funding available to forestry still remains small relative to the scope of the problem. International development assistance organizations cannot fund enough forest conservation to offset deforestation because the underlying institutional causes can only be resolved by the tropical countries themselves.

IMPORTANCE OF TROPICAL FOREST RESOURCES

For tropical nations, forests and shrublands provide wood for lumber and paper, building materials, and fuel, and are an important source of foreign exchange. Forests help maintain soil quality, limit erosion, stabilize hillsides, modulate seasonal flooding, and protect waterways and marine resources from accelerated siltation. In addition, many millions of people living in and near the forests depend directly on them for food, medicines, and other basic needs.

The benefits from tropical forests are not limited to tropical nations. World trade in tropical wood is significant to the economies of both the producing and consuming nations. The United States is the second largest importer of tropical wood products, and U.S. demand for tropical wood has been growing at rates well above our population and gross national product growth rates. Tropical forests also provide a broad array of nonwood products such as oils, spices, and rattan that are valuable for both subsistence and commerce. The annual world trade in rattan, for example, is estimated to be $1.2 billion. Thus, industrial wood and other forest product exports earn substantial foreign exchange for nations that trade with the United States.

The productivity of renewable resources in the Tropics affects both the economic viability of U.S. investments overseas and political stability in the tropical nations. Many development projects funded by the U.S. Government or the U.S. private sector are being undercut by flooding, siltation of reservoirs, pest outbreaks, and other problems associated with deforestation. Food and jobs, both critical for political stability in developing nations, can be reduced by the consequences of deforestation.

The highly diverse tropical forests contain plants, animals, genetic material, and chemicals that have great potential value for medicine, agriculture, and other industries. The Tropics are thought to contain two-thirds of the world's approximately 4.5 million plant and animal species. An estimated 2.5 million of the tropical species are yet unknown to science. Considering the value to society that has come from those tropical species that have been studied (e.g., many major agricultural crops, anticancer drugs, insects used in integrated pest management), it is very likely that some of the remaining unstudied species offer potentially important resources, particularly for pest control, plant breeding, genetic engineering, and other biotechnologies. Biologists are already using new techniques for cloning plants and micro-organisms to screen for their production of useful chemicals.

Tropical forests also provide habitats for many of the world's migratory birds and various endangered species. About two-thirds of the birds that breed in North America migrate to Latin America or the Caribbean for winter. Some of these migratory birds play an important role in controlling agricultural pests in the United States.

STATUS OF TROPICAL FORESTS

Some 76 nations located entirely or largely within the tropical latitudes contain about half the world's population (approximately 2 billion). These nations are characterized by rapidly growing populations, low per capita incomes, and predominantly agrarian economies. Near forest lands, much of the agriculture is subsistence farming, often in upland areas where soils are dry or have low fertility. Commercial agriculture, on the other hand, generally is sited on the more fertile and often irrigated alluvial plains of major river valleys. Both types of agriculture are strongly affected by the 1.2 billion hectares* of moist tropical forest and 800 million hectares of drier open woodlands.

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*One hectare equals 2.47 acres.

The type and distribution of forests vary considerably across regions in the Tropics (fig. 5). Two-thirds of the closed forests* are found in tropical America, while Africa has two-thirds of the open forests.** Even within regions, forest types are unequally distributed among countries.

Data on the extent and condition of tropical forests are widely scattered and often inaccurate. Overall figures for deforestation* mask

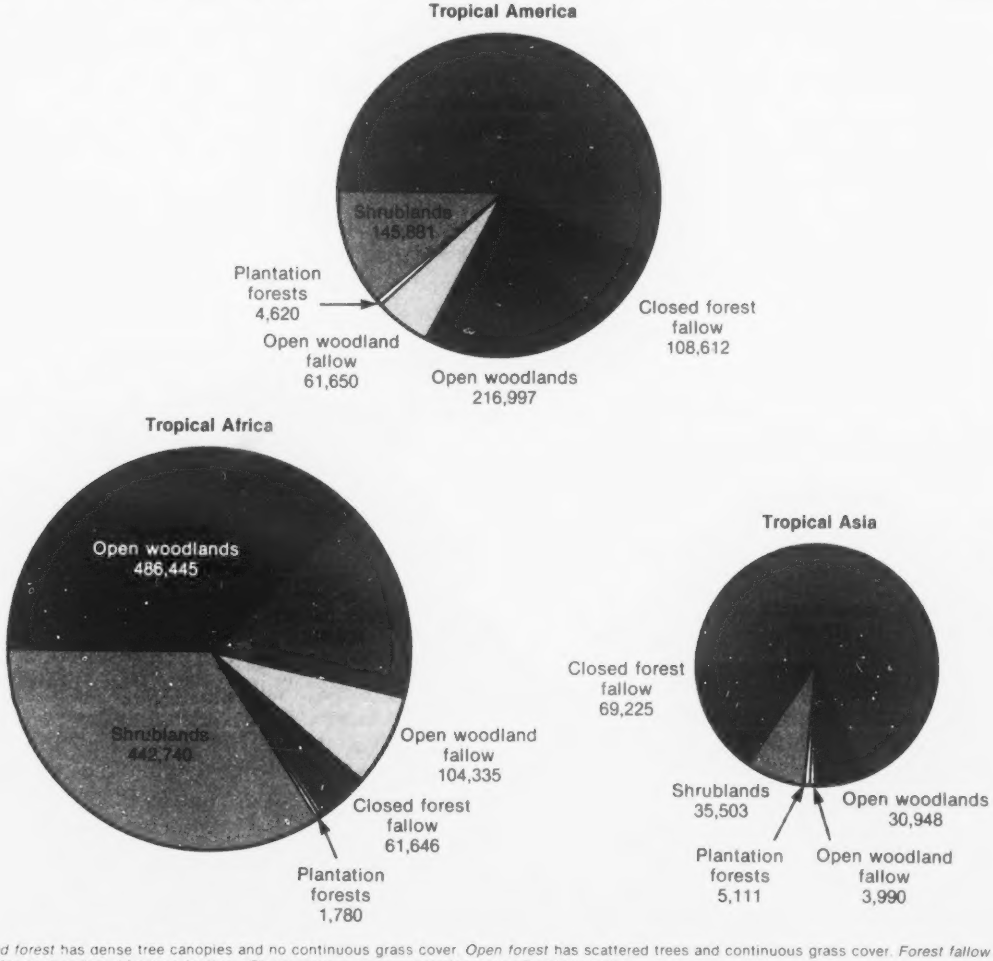
---

*Closed forest means that trees shade so much of the ground that a continuous layer of grass cannot grow.

**Open forest has trees that cover at least 10 percent of the ground but still allow enough light to reach the forest floor so that a dense, continuous cover of grass can grow.

*Deforestation is the conversion of closed or open forest to nonforest. A distinction should be made between deforestation and degradation; the latter refers to biological, physical, and chemical processes that result in loss of the productive potential of natural resources in areas that remain classified as forest. This distinction explains some of the confusion in estimates of change in forest resources.

Figure 5.—Areas of Woody Vegetation[a] in 76 Tropical Nations (thousands of hectares, 1980 estimates)



[a] *Closed forest* has dense tree canopies and no continuous grass cover. *Open forest* has scattered trees and continuous grass cover. *Forest fallow* is land used for or abandoned from agriculture. *Shrubland* has wood vegetation under 7 meters high.

SOURCE: Office of Technology Assessment

considerable differences among the rates at which individual countries are using and altering their forest resources (table 1). If present trends were to continue, nine tropical countries would eliminate practically all of their closed forests within the next 30 years and another 13 countries would exhaust theirs within 55 years.

Estimates of overall deforestation rates also conceal significant differences in the types of tropical forest affected. The loss of species is probably greatest in the broad-leaved humid lowland forests as these are biologically the most complex and diverse. But the tropical conifer forests cover much smaller areas and have been severely degraded by logging and agriculture. Direct impacts on people are greatest in dry regions where degradation of open forests leads to severe shortages of wood for fuel. But the loss of mountain watershed forest may affect even more people by making river flows more erratic.

Each year approximately 11.3 million hectares of the Earth's remaining tropical forests —an area roughly the size of Pennsylvania— are cleared and converted to other uses. Where cleared land is developed for sustainable agriculture, deforestation can be beneficial. But most land being cleared cannot sustain farming or grazing with available technologies. So it is abandoned after a few years. Often, commercially valuable trees do not grow back quickly because of highly weathered soils, harsh climates, and recurring fires. Thus, productive but underused forest resources are giving way to low productivity grasslands and deserts.

Deforestation and degradation of tropical lands are not new. Losses of forest resources have been reported as early as 450 B.C. in the African Sahel and 1000 A.D. in South China. For centuries, tropical deforestation has been associated with poverty and with patterns of economic development that result in inequitable access to farmland. People displaced by development in the lowlands often have been the direct agents of deforestation because they have little choice if they are to survive.

The main agents of tropical deforestation and forest resource degradation continue to be subsistence agriculturalists, livestock raisers, fuelwood collectors, and people who set fires to facilitate clearing or gathering activities. Commercial agriculture plays a smaller role in deforestation today than it has in the past, although in some areas (e.g., Central America and Brazil) clearing tropical forests for cattle ranching causes a large part of the forest resource loss. Commercial logging is also an important cause of forest degradation.

Both subsistence and commercial use of forest lands can cause deforestation. Combined, they form particularly pernicious relationships. For example, loggers build roads through undisturbed forests to remove timber. Slash-and-burn cultivators use the roads to gain access to the forests and clear patches for temporary agriculture. Ranching or commercial agriculture may follow the farmers, exploit the land's remaining productivity, then move on into new areas. These agents of tropical forest change vary in prominence among tropical America, Africa, and Asia.

Alternative techniques exist that could be substituted for these destructive practices. However, sustainable forestry and agriculture practices generally are not being developed and applied. The underlying causes of this failure lie in political, economic, and social forces (e.g., undefined property rights) that cause people to use forests in ways that are inappropriate to ecological conditions. Deterioration of the forest resources seems likely to continue until combinations of improved technologies and enforced resource development policies make sustaining the forests more profitable than destroying them.

Table 1.—Estimates of Closed Forest Areas and Deforestation Rates in Tropical Africa, America, and Asia

Country	Closed forest area (1,000 ha)	Percent deforested per year[a]
Tropical Africa:		
Ivory Coast	4,458	6.5
Nigeria	5,950	5.0
Rwanda	120	2.7
Burundi	26	2.7
Benin	47	2.6
Guinea-Bissau	660	2.6
Liberia	2,000	2.3
Guinea	2,050	1.8
Kenya	1,105	1.7
Madagascar	10,300	1.5
Angola	2,900	1.5
Uganda	765	1.3
Zambia	3,010	1.3
Ghana	1,718	1.3
Mozambique	935	1.1
Sierra Leone	740	0.8
Tanzania	1,440	0.7
Togo	304	0.7
Sudan	650	0.6
Chad	500	0.4
Cameroon	17,920	0.4
Ethiopia	4,350	0.2
Somalia	1,540	0.2
Equatorial Guinea	1,295	0.2
Zaire	105,750	0.2
Central African Republic	3,590	0.1
Gabon	20,500	0.1
Congo	21,340	0.1
Zimbabwe	200	[b]
Namibia	[b]	[b]
Botswana	[b]	[b]
Mali	[b]	[b]
Upper Volta	[b]	[b]
Niger	[b]	[b]
Senegal	220	[b]
Malawi	186	[b]
Gambia	65	[b]
Totals	216,634	0.61
Tropical America:		
Paraguay	4,070	4.7
Costa Rica	1,638	4.0
Haiti	48	3.8
El Salvador	141	3.2
Jamaica	67	3.0
Nicaragua	4,496	2.7
Ecuador	14,250	2.4
Honduras	3,797	2.4
Guatemala	4,442	2.0
Colombia	46,400	1.8
Mexico	46,250	1.3
Panama	4,165	0.9
Belize	1,354	0.7
Dominican Republic	629	0.6
Trinidad and Tobago	208	0.4
Peru	69,680	0.4
Brazil	357,480	0.4
Venezuela	31,870	0.4
Bolivia	44,010	0.2
Cuba	1,455	0.1
French Guiana	8,900	[b]
Surinam	14,830	[b]
Guyana	18,475	[b]
Totals	678,655	0.6
Tropical Asia:		
Nepal	1,941	4.3
Sri Lanka	1,659	3.5
Thailand	9,235	2.7
Brunei	323	1.5
Malaysia	20,995	1.2
Laos	8,410	1.2
Philippines	9,510	1.0
Bangladesh	927	0.9
Viet Nam	8,770	0.7
Indonesia	113,895	0.5
Pakistan	2,185	0.3
Burma	31,941	0.3
Kampuchea	7,548	0.3
India	51,841	0.3
Bhutan	2,100	0.1
Papua New Guinea	34,230	0.1
Totals	305,510	0.6

[a] From 1981-85.

[b] No data; in most cases this is where the areas are very small.

SOURCES: Food and Agriculture Organization/United Nations Environment Programme, *Tropical Forest Resources Assessment Project (GEMS): Tropical Africa, Tropical Asia, Tropical America*, 4 vols., Rome, 1981.

TECHNOLOGY ASSESSMENT

This report discusses various technologies to develop tropical forest resources. Some are techniques to manage forests—undisturbed and disturbed—and some are technologies to use forests to protect related resources such as agriculture and water. Others are techniques to prepare people for the various tasks involved in developing and implementing technologies to sustain the resources.

Technologies for Undisturbed Forests

Undisturbed forests produce many valuable products and services, usually with little or no human management. One way to reduce the rate at which undisturbed forests are converted to other, nonsustainable uses is through systematic preservation of sample ecosystems in parks and protected areas. Another approach is to enhance the value of the forest by developing its resources other than timber—the nonwood products and forest food sources. For either approach to succeed, willing involvement of local people and political commitment from government decisionmakers are essential.

Maintaining Sample Ecosystems

Parks and protected areas can be managed for direct income (e.g., tourism) and for indirect benefits, such as preventing siltation of reservoirs. Some of these benefits can be estimated for resource allocation decisions. Other major benefits provided by protected areas—e.g., preservation of biological diversity—cannot be measured in dollars. Thus, in the past, the locations of protected areas have been determined more for watershed protection or tourist potential than for conserving of biological diversity.

A marked disparity exists in the worldwide distribution of parks and protected areas, with some types of ecosystems well represented and others not represented at all. Many legally protected areas lack firm commitments from local, national, and international agencies. Consequently, they receive little actual protection or are inadequately managed.

Strict preservation with total exclusion of economic activity is not practical for many sites where protection of undisturbed forests is important. Recognizing the growing demands to develop rural land, protected area planners and managers have begun to pay more attention to socioeconomic and institutional factors. They seek participation from both the people who will affect or be affected by forest resources and the people and agencies that must support management programs.

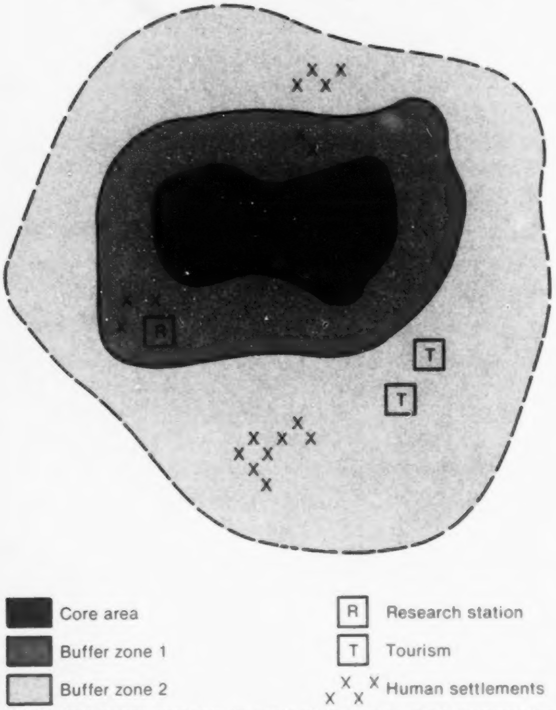
Some innovative plans that include the surrounding biophysical and socioeconomic setting have been developed for protected areas. One such activity is the UNESCO Man and the Biosphere (MAB) program's worldwide network of biosphere reserves (fig. 6). The management of these reserves considers the needs of local populations and seeks ways to make benefits available to local people. More field experience and monitoring are needed to evaluate the successes of existing biosphere reserves. However, the MAB effort is constrained by a lack of strong, consistent commitments from U.S. and other governments.

Making Undisturbed Forests More Valuable

Few deliberate attempts have been made to harvest forest products other than timber and fuelwood in a sustainable, organized way. Incentives to maintain unlogged forests would be greater if methods were developed to use forest resources other than timber more fully—either by discovering new, valuable products or by encouraging collection and processing of existing products.

Products obtained from animals and from wood, bark, leaves, or roots of trees and other forest vegetation offer significant opportunities for tropical countries to develop cottage industries. Employment and incomes for people living in or near forests could be improved while encouraging maintenance of the natural ecosystems. Improved assessment of the role of

Figure 6.—A Typical Biosphere Reserve



A biosphere reserve considers the needs of the local people by incorporating biophysical and socioeconomic factors into its management plan.

SOURCE: M. Batisse, "The Biosphere Reserve: A Tool for Environmental Conservation and Management," *Environmental Conservation*, vol. 9, summer 1982.

forest products in subsistence economies and development of markets for nonwood products could help decisionmakers recognize the value of undisturbed forests. U.S. scientific and managerial expertise could be applied to this problem, especially from the fields of ecology, botany, business, and forest management.

Few technologies exist today that can extract selected renewable resources from a tropical forest while leaving the forest nearly intact. Crocodile and butterfly farming are two examples that are being implemented. The development of other such resource-conserving systems is needed.

Technologies to Reduce Overcutting

Much resource degradation is caused in closed tropical forests by inappropriate wood harvesting methods and in mountain and dry forests by cutting more wood than grows each year. Development of improved wood processing technologies and markets for more of the many tree species and sizes growing in the closed forests would reduce the area that must be logged to satisfy timber demand. Where too much wood is being cut, it may be necessary to reduce demand by increasing the efficiency of woodstoves and charcoal kilns or by substituting alternative energy sources.

Industrial Wood

Intensive forest harvesting could give increased output per unit area, thus reducing demand to cut elsewhere. But this approach can have both positive and negative impacts. It can make reforestation planting more feasible. On the other hand, it increases the potential for damage to the site from poor road engineering, inadequate site protection, and tardy restoration of forest stands. Intensive harvesting would require strict enforcement of regulations to prevent adverse impacts on the land's long-term productivity.

Intensive harvesting depends on the availability of profitable technologies to extract, process, and market a wider range of tree species and sizes. Grouping species according to their uses (e.g., construction material) is an approach that has been successful in Africa. However, many unused species have sizes, shapes, or wood characteristics that make them difficult to harvest and process and that limit their usefulness.

The use of smaller trees would require costly replacement of existing equipment, which has been designed for large logs. Portable sawmills and small units that could be carried easily and set up to mill logs at the stump could make logging much more efficient. Such technologies might minimize adverse environmental effects from hauling logs but might encourage logging of currently inaccessible areas.

The greatest progress toward making intensive harvest profitable has occurred where multispecies wood chips are produced for wood pulp or fuel. The "press-dry paper process" developed at the U.S. Forest Products Laboratory promises to increase the world market for hardwood chips. However, chipping can have adverse impacts because in moist tropical forests most of the plant nutrients are located in the trees rather than in the soil. Thus, wood chip harvesting that removes most trees can severely reduce the fertility of the site.

For little known but potentially marketable lumber species, cost-effective preservation and drying technologies are needed to improve use characteristics. Many types of wood are susceptible to attack by termites, other insects, or fungi under tropical conditions. Although wood preservatives are available, they generally are costly. Some less expensive techniques exist but their effectiveness has not been proven.

Fuelwood

Approximately 80 percent of the estimated 1 billion cubic meters of wood removed annually from tropical forests is used for fuel. The effects of excessive fuelwood cutting are seen first near cities and towns where fuel demand is concentrated. But overcutting does not always remain a local problem. Mangrove forests of Thailand and dry forests of Kenya, for example, are overcut to produce charcoal that is transported by ship to other nations.

Most wood fuel is used in homes for cooking, though tobacco drying and other rural industries also consume substantial quantities. Common domestic stoves waste much of the wood energy, as do traditional methods of making charcoal. Therefore, it should be possible to reduce fuelwood demand significantly and consequent overcutting by disseminating more efficient stoves and charcoal kilns.

Attempts to introduce such technologies in tropical nations have had mixed success. Improved stoves are not quickly and widely accepted. Though cheap by U.S. standards, they often cost too much. Some reduce the range of fuels that can be used. Further, improved charcoal production sometimes does not lead to less wood cutting because charcoal makers may use the time or profits they gain to make even more charcoal. Techniques to reduce demand require especially careful planning, monitoring, and evaluation.

Photo credit: OTA staff

Since most wood fuel in tropical nations is used in homes for cooking, disseminating more efficient and low-cost stoves should significantly reduce fuelwood demand

Nonwood fuels such as kerosene can sometimes be used to reduce wood demand temporarily while fuelwood plantations are established and while natural forests recover from exploitation. But the costs of obtaining and distributing nonwood fuel substitutes are often prohibitive, especially to the rural poor. Small-scale, renewable energy technologies such as solar dryers have more potential for long-term use, but their adoption is inhibited by financial and managerial constraints.

Substituting plantation-grown wood for natural forest wood clearly is an important option in many tropical regions. Investment in plantations is constrained, however, where access to "free-for-the-taking" forest wood is not restricted. Thus, regulatory controls on fuelwood gathering from the natural forest must be enforced if the fuelwood plantation option is to be used before all the accessible natural forests are destroyed. Where fuelwood has commercial value above the cost of cutting and transportation, there is a possibility that farmers and business will invest in planting trees.

Securing future wood supplies is a social, political, and economic problem. Investments of land, labor, and capital in tree growing are constrained by problems with land ownership, laws, and social organization. Until these are resolved and woodfuel supplies are being effectively replenished, measures to reduce demand will fail to reach the root of the problem. Demand reduction creates no incentives for increased supply; it may achieve the reverse.

Technologies for Disturbed Forests

An estimated 400 million hectares of potentially productive secondary forest* exist in closed tropical forest areas. Approximately 2 billion hectares of tropical lands are in various stages of degradation. Investment in the improvement of secondary forests and reforestation of degraded lands offers opportunities to meet needs for materials, substitute domestic production for imports, and provide new sources of employment in wood production and processing.

Management of Secondary Forests

Many tropical countries could sustain production of all the wood they will need for decades if adequate investments were made to develop and manage cutover secondary forests. However, such investments are seldom made. Land tenure can be a constraint, but even where the forests are clearly owned and controlled by government forestry agencies or private landowners, investments are usually inadequate. Technologies for sustained forest production exist, but for most of these the time lag before payback begins is too long and return on the investments is too low to attract adequate private and public capital. Opportunities to improve this situation include:

- resolution of land tenure issues,
- public and private investments in research and development to make sustainable secondary forest management more profitable,
- increased technology transfer of profitable resource-sustaining forest management methods, and
- implementation of resource use regulations, tax laws, or subsidies to make investments in secondary forest management more profitable.

Simply reducing logging damage by using appropriate or improved harvesting equipment can increase the number of trees available for a future crop as well as increase natural regeneration and facilitate enrichment planting. But to ensure that this occurs, regulations to control logging practices must be enforced.

Reforestation of Degraded Lands

Technologies are available to reforest certain degraded lands. But tree planting sometimes does not compete well, in economic terms, with other land uses. The solutions to this dilemma include reducing reforestation costs, reducing plantation failure rates by enlisting support of local people, increasing plantation yields, and developing methods to quantify the indirect benefits of reforestation.

Reforestation costs can be reduced if land preparation is used to reduce weed invasion and ensure a favorable environment for seedling growth. Plantation yields can be increased by selecting high-yielding, fast-growing, soil-enriching, and stress-tolerant tree species. Developing and implementing tree breeding and improvement programs can produce varieties with high yields and other desired characteristics. Careful provenance testing—matching the appropriate variety to a particular site—should improve species performance and reduce mortality.

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*Secondary forest includes both residual forest that has been cut once or several times during the past 60 to 80 years and second growth forests that invade after periodic cultivation.

To achieve successful reforestation, several constraints must be overcome:

- shortage of planting stock and lack of quality control in seed and clone production,
- inadequate knowledge of tropical site conditions, and
- lack of information dissemination.

The coordination of collection, certification, and international distribution of high-quality seeds in commercial quantities needs to be improved. Information on proven silvicultural techniques must be disseminated to the local people.

These technical problems can be solved given adequate funding and time. A more subtle problem is to get local people to maintain tree plantations. First of all, they must clearly understand the reasons for planting trees. The trees should produce products local people want, and the people must be convinced that substantial benefits from the trees will accrue directly to them. Often this means using species selected by local people rather than species selected by foresters.

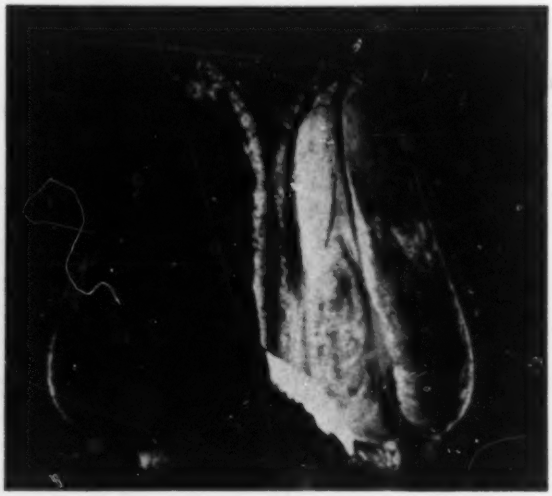

Photo credit: J. Bauer

Mahogany seed. Shortage of planting stock and lack of quality control in seed production are constraints to reforestation. Systematic collection, certification, and distribution of seeds in commercial quantity could facilitate tree planting

Forestry Technologies to Support Tropical Agriculture

Medium- and long-term maintenance of tropical forest resources may depend more on sustaining the land already under cultivation than on refining use of the remaining forest. Introducing woody perennials into farming and pastoral land (agroforestry) and improving farming techniques for upland watershed areas could help sustain the productivity of lands under cultivation and so reduce the need to clear additional forest lands.

Agroforestry

Agroforestry encompasses many well-known and long-practiced land-use methods. The aim is to create productive farming systems able to supply a higher and more sustainable output of basic needs and saleable products than occurs without trees. Agroforestry is most important on lands with serious soil fertility problems and lands where inadequate rural infrastructure makes it vital for people to produce most of their own basic needs for fertilizers, food, fodder, fuel, and shelter.

Agroforestry is a newly recognized field and could benefit from a critical examination of practices and quantification of information. Since agroforestry cuts across several disciplines, its research and development requires an interdisciplinary approach. Because of fragmented institutional jurisdiction, however, agroforestry is not receiving adequate support from either forestry or agricultural institutions.

Great technological potential for agroforestry seems to lie in genetic improvement (systematic breeding and selection) of multipurpose tree and shrub species. Selection of appropriate provenances, subspecies, and varieties can greatly enhance the success of agricultural systems designed for particular land requirements.

The potential for farmers and pastoralists actually to adopt agroforestry system improvements is more difficult to assess. Peasant farmers can ill afford the risks of innovation. Large-

Photo credit: H. Bollinger

Production agroforestry system (planting *Eucalyptus* fuelwood trees, coffee, fodder grasses, and sisal fiber crops on terraces) in Kenya. Such land-use systems could have great impact on sustaining tropical forests

scale adoption of new agroforestry systems would require creating incentives for people to implement new practices in spite of the initial risks and delayed returns.

Watershed Management

The greatest problems in tropical watersheds occur where subsistence farmers and their livestock move onto steep uplands. Excluding farmers and livestock from such areas can allow vegetation time to recover, but enforcing such policies is difficult. Mechanical structures and replanting methods can restore water flow stability from some deforested slopes. Further, conservation practices exist that allow farming and grazing on many moderate watershed slopes. However, the watershed management techniques are unlikely to become widespread until farmers and herders in upland areas have incentives to stop destructive land-use practices. To provide upland farmers with nondestructive land-use alternatives necessitates:

- developing methods of land use that are more profitable to the local community and at the same time improve control of water flows;
- developing improved techniques to measure and predict tradeoffs of different management actions; and
- testing new technologies and getting the useful ones adopted by the local community. Subsidies from downstream beneficiaries of the watershed protection may be necessary. Sociological studies could help define the type of incentives needed to obtain farmers' cooperation.

Resource Development Planning

Most conversions of tropical forests to other land uses take place without adequate consideration of whether the natural and human resources available can sustain the new land use. Sometimes, destructive forest conversions are an unplanned result of some other, narrowly planned development. For instance, poorly sited logging roads can open highly erodible forest land to unplanned clearing for slash-and-burn agriculture.

This problem can be ameliorated through the use of resource development planning techniques that match land development activities to the natural and human capabilities of specific sites. These techniques can identify which sites can sustain crop production, grazing, reservoirs, new settlements, intensive forestry or agroforestry, and which will be most productive if retained as natural forest.

Ideally, resource development planning includes four components: biophysical assessment, financial (investor's viewpoint) and economic (society's viewpoint) assessment, social assessment, and project monitoring and evaluation. Biophysical assessment is used more often than the others, although it still is underused. Furthermore, the techniques commonly are used to find the best site for a particular development purpose rather than to develop a comprehensive strategy for all sites in a region.

Use of each of the four planning components is constrained by a lack of information on cause-and-effect relationships. Economic assessment encounters difficulty measuring nonmarket values. Further, the analyses may consider the forest values only of a small site, disregarding the interrelationships between that site and the surrounding area. For example, loss of the genetic resources in a small patch of a large forest may seem unimportant because nearby forested areas contain the same biological diversity. Consequently, individual economic analyses may justify clearing the forested region piece by piece without accounting for the overall genetic loss incurred.

Finally, even well-planned development may prove unsustainable if planning stops after implementation begins. Most planning is done before projects begin when least is known about biophysical and human resources at the site. Continuous planning, monitoring, and evaluation are necessary during and after the project. The major development assistance organizations have begun to institute such procedures but have not yet determined how to use the results.

Opportunities to enhance the use of resource development planning include improving data availability, more demonstration of the techniques' potentials, better communication of planning successes, increasing the number of trained planners, improving techniques for economic and social analysis, and assuring that projects remain open to redirection after implementation begins.

Education, Research, and Technology Transfer

Forest resource development is constrained in most tropical nations by a shortage of professional and technical personnel who know about appropriate technologies and who also understand the institutional, economic, and cultural aspects of forest resource systems. In the near term, expatriates, including U.S. professionals, can provide some expertise. But this is not likely to be sufficient because the scope of tropical forest resource problems is so large and the number of expatriate experts is few. Further, expatriates lack the political and cultural ties necessary to influence policy. Sustaining tropical forest resources requires development of indigenous expertise in all aspects of resource development. Education, research, and technology transfer are the means to develop expertise both in the United States and in tropical nations.

Education

U.S. universities can act to sustain tropical forests in two ways: educating professionals who will work in tropical forestry related fields and strengthening tropical nations' universiies. However, tropical forestry is peripheral to the interests of most U.S. forestry schools and the experts are scattered widely among institutions. Consequently, efficient mechanisms must be developed to bring together multidisciplinary teams of researchers and educators and connect them with students, foreign universities, and others seeking to develop tropical forest expertise.

Twinning, which creates associations between tropical nation institutions and individual developed nation institutions, has worked with a few university forestry schools. Consortia of U.S. universities can provide tropical institutions access to a wider range of expertise and experience than twinning arrangements. However, this approach still does not resolve several of the fundamental deficiencies that reduce the effectiveness of U.S. institutions. U.S. forestry schools lack a tropical setting for teaching and research. Further, their curricula do not prepare students to solve the social and institutional problems that confront tropical forest resource development.

The development of one or more U.S. centers of excellence in tropical forestry might resolve these deficiencies. For example, a center of excellence in Puerto Rico could focus on Latin American forest development needs, providing the necessary tropical setting as well as benefiting the U.S. tropical forests.

A major objective of U.S. efforts to enhance tropical forest education could be to strengthen schools in the Tropics. Some 138 universities and 220 technical schools in tropical nations provide forestry education and training. Nearly all these schools are new. Most are small and produce few graduates each year. Thus, substantial support is needed to provide in-service faculty training, to produce locally relevant course materials, and to modernize basic education facilities such as herbariums, library collections, and computers.

Resource development professionals, the scientists who develop technologies, and the technicians who implement them are ineffective without strong support from the many people who make decisions about the use of natural resources. Environmental education aims to change people's attitudes and behavior by providing them with the motivation and the knowledge necessary to make decisions and take actions that will sustain natural resource productivity.

Environmental education efforts can be directed at the general public using mass media or programs in primary and secondary schools. Or the efforts can be directed more narrowly at higher level decision makers. Unfortunately, the behavioral science basis for environmental education is not well established, so the techniques must be developed by unscientific trial and error. This development could be accelerated if significant investments were made to evaluate, document, and communicate the environmental education efforts that are under way. Having neither a strong scientific foundation nor substantial documentation of the causes of program success and failure, environmental education projects have a difficult time competing with other projects for funds and personnel.

Research

Technologies intended to develop renewable resources are likely to fail if they are based on inadequate knowledge. Thus, both fundamental and applied research are necessary components of any strategy to sustain tropical forest resources. Fundamental research is the foundation for applied research, while applied research is needed to improve existing forestry technologies and develop new ones.

Many experts conclude that sustaining tropical forests is not so much a technical problem as it is an institutional problem. Thus, research is especially needed to determine the interactions between the social and biophysical factors of tropical forest systems. Some knowledge about social and institutional factors is being used in resource development projects supported by U.S. agencies. However, this knowledge usually is based on personal experience, not on careful research. A substantial increase in truly interdisciplinary research could enhance the likelihood that institutional changes would result in sustainable forest resource development.

The techniques used to manage tropical forest resources are generally based on trial-and-error experience gained in past centuries. They have benefited little from the rapid advances in fundamental and applied biology that have occurred recently. **For most tropical forest types, techniques have not been developed that can:**

- produce the products, environmental services, and employment opportunities that local people need, *and*
- sustain the productivity of the resource base, *and*
- be profitable enough to motivate people to risk their scarce capital, labor, and land.

Applied research to improve existing technologies probably will not suffice to meet these goals. Innovations based on new fundamental research will also be necessary.

Low levels and short periods of funding are major constraints on fundamental research in tropical areas, but these are not the only reasons why basic knowledge is inadequate to sustain tropical forests. Most fundamental research in tropical biology has been designed to develop evolutionary theory, and relatively little work has been done or is being done on ecological theory.

Another problem is poor communication among researchers and between researchers and technology users. Most forestry and biology research organizations reward scientists, including those working on applied research, for publishing in journals that technology users seldom read. In fact, few journals exist that are designed to communicate research results to resource developers. The U.S. Forest Service periodical *The Caribbean Forester* once served this purpose but has been discontinued. As a result of poor communication, the pace of innovation is slower than it needs to be, techniques are reinvented, some mistakes are continually repeated, and potentially successful technologies spread slowly, if at all.

Technology Transfer

The experience of U.S. forestry organizations shows that many potentially profitable techniques languish for lack of effective technology transfer among scientists, between scientists and technology users, and among technology users. Thus, it is appropriate that international development assistance organizations focus their efforts not on promoting particular technologies but rather on building local institutions' capacities to choose, receive, adapt, and deliver technologies appropriate to local circumstances.

An important constraint on development assistance effectiveness in forestry is the lack of coordination among many bilateral and multilateral projects. Coordination of resource development projects so that each project contributes the appropriate actions at the appropriate time to accomplish long-range plans should be the responsibility of tropical governments. But donor agencies usually fund the projects they identify rather than projects identified in some longer term planning process. One approach to improve planning and coordination of technology transfer is the use of ad hoc international committees that are separate from the policies and problems of individual government agencies or development assistance organizations. Committees such as the newly instituted Coordination for Development in Africa could assist tropical governments in developing long-range plans and in identifying and recommending projects for the various international organizations.

The OTA assessment identified a number of necessary conditions for successful technology transfer.* For most technologies, the lack of these conditions seems to be constraining wider adaptation and adoption:

- Technology is transferred most effectively by direct people-to-people actions. People who are to adapt and apply the technology need to learn it directly from people who have experience applying it.

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*These conditions were a result of discussions among OTA staff; Roger Moeller, AID; and Gary Eilerts, Appropriate Technology International.

- The technology needs to be adapted at the users' end to local biophysical and socioeconomic conditions.
- Well-qualified people with knowledge about the technology are needed on the source end of the transfer, and receptive, capable people are needed on the receiving end. These people may be local transfer agents or they may be the end users.
- Another type of actor, the "facilitator," is also necessary. Facilitators understand the technology transfer process, including the market for the technology and its products and the political, social, and economic constraints and opportunities that affect all the other actors.
- Users and transfer agents should be involved in choosing the technologies and in planning and implementing the transfer process so that the technology and the transfer meet actual needs and are appropriate for the local situation.
- All parties involved—source, transfer agents, facilitators, and end users—must feel that they are winners and must, in fact, be winners. Each actor's self interests should be identified at the start of the technology transfer process so that they can be addressed.
- Each participant must be aware of subsequent steps in the transfer process so his or her actions are appropriate to the later steps. This requires early definition of roles for each person involved.
- The environment for technology demonstrations should be similar to the environment that will exist during subsequent steps of the transfer process. Pilot transfer projects should not be unrealistically easy.
- The initial commitment of resources to the process should be sufficient to carry the technology transfer until it is self-supporting.
- The transfer process must include mechanisms through which all participants can contribute effectively to interim evaluations and improvements.

ISSUES AND OPTIONS FOR CONGRESS

Tropical forest resources represent a great opportunity for sustained development because they are fundamentally renewable. However, too little such development is occurring. Instead, the productivity of the forests continues to be diminished. The U.S. Congress has already helped to sustain tropical forests by directing AID and the U.S. representatives to international organizations to give forest resource development higher priority in development assistance programs. To expand this progress, Congress could take actions that would enhance tropical governments' abilities to plan and coordinate resource development projects.

The underlying causes of forest resource deterioration are institutional, social, and economic. Consequently, the reforms needed to support sustainable resource development can only come from the governments and people of the tropical nations. However, the United States can help stimulate such reforms. Some U.S. technologies, such as Landsat imagery, already supply vital information to improve resource development decisions. U.S. diplomacy—for example, supporting the United Nations Environment Program and UNESCO's MAB program—also can help to foster understanding of resource problems and coordinate international efforts to resolve them.

Congress can address technical constraints more directly. U.S. and international organizations that Congress can influence have the capability to: 1) develop technologies to produce goods and services for local people while conserving forest productivity, and 2) assist tropical organizations and individuals in developing, adapting, and implementing such technologies. U.S. agencies that are applying this type of expertise include AID, the Forest Service, the National Academy of Sciences, the National Park Service, the Fish and Wildlife Service, and the Soil Conservation Service. Some commercial firms, private voluntary organizations, and U.S. universities also have expertise relevant to sustaining tropical forest resources.

Congress has ways to influence multilateral banks and U.N. agencies, some obvious (e.g., through allocation of funds) and some subtle (e.g., using the prestige of Congress to give credibility to a new idea). The final chapter describes opportunities for congressional action to:

- expand and coordinate development assistance,
- encourage resource development planning,
- improve tropical forest research and development efforts,
- protect biological diversity, and
- expand U.S. expertise in tropical forest resources.

The U.S. tropical forests are discussed separately in this summary.

Expand and Coordinate Development Assistance

Issue (Projects)

Development assistance progress is slow and the gains are insufficient to sustain tropical forest resources. Many opportunities exist to enhance gains already made, but congressional vigilance is necessary to ensure that forestry projects receive an appropriate share of U.S. development assistance funds and that other types of projects complement the forestry efforts.

The Foreign Assistance Act directs development assistance organizations in which the United States participates to give higher priority to protecting against the loss and degradation of tropical forests. Accordingly, AID, the World Bank, the U.N. Food and Agriculture Organization (FAO), and some other multilateral organizations have increased funding in recent years for forest related projects. However, many opportunities for use of development assistance to sustain tropical forest resources are not being pursued adequately. Examples of such opportunities are:

- emphasize agroforestry, innovative crops, and other techniques to sustain permanent agriculture on relatively poor soils;
- promote reforestation and management of natural forests to sustain environmental services and produce fuelwood, construction wood, polewood, and nonwood products;
- stress institution-building to enable tropical governments to exercise improved control over timber concession operators; and
- support livestock projects that do not result in deforestation or forest degradation.

Option

To encourage expanded support for forestry projects, committees of Congress could continue oversight hearings requesting AID officials and U.S. representatives to multilateral development assistance organizations to testify on the extent to which assistance practices accomplish the objectives set forth in section 118 of the Foreign Assistance Act.

Issue (Coordination)

Development assistance agencies generally do not coordinate their projects effectively at the country or regional level. To improve their effectiveness, projects could be organized as steps in comprehensive strategies designed to develop sustainable forest resource use systems. Individual development assistance agencies have neither developed nor coordinated such strategies.

The reasons why host governments and international assistance organizations do not coordinate activities more effectively are complex. But coordination could play a key role in improving the cost effectiveness of U.S. assistance. If the Congress decides that improving cost effectiveness is worth relinquishing some degree of U.S. control over what projects are funded, it could mandate increased U.S. effort to enhance the tropical nations' abilities to coordinate the work of development assistance organizations.

Options

One way to begin such a fundamental shift in the development assistance process would be to direct the Department of State to assess whether various tropical nations are able and politically ready to develop long-term action plans for sustained forest resource development. Another mechanism is to create ad hoc committees of experts from donor nations and tropical nations to work together to identify problems and plan regional forest development strategies.

Encourage Resource Development Planning

Issue

Although resource development planning technologies can improve the sustainability of tropical forest development, they are seldom applied to their full potential.

Resource development planning techniques can be used to identify development activities that match the available human and natural resources. The techniques can give decisionmakers a clearer picture of the social, economic, and environmental implications of a particular type of development on a particular site. Also, they can be used to determine the best locations for protection of natural areas to maintain biological diversity while providing tangible benefits. But the application of planning is hampered by shortages of information on how biophysical, social, and economic factors interact.

Options

To encourage the use of resource development planning, Congress could maintain the availability of low-cost Landsat images to tropical governments. Congress also could direct AID to expand its Environmental Profiles to include macro-level land classification and collection of information for social and institutional analyses. Further, Congress could direct U.S. representatives to multilateral development banks to promote environmental assessments at an early stage of project planning. This request could be followed up with hearings to determine whether the banks are using environmental assessment procedures effectively.

Improve Tropical Forest Research and Market Development

Issue (Research)

Fundamental research, applied research, and technology implementation related to tropical forests are not well coordinated. Moreover, interactions among factors that constrain forest resource development are poorly understood. Consequently, resource development projects often fail and technologies that seem to succeed in trials fail to spread beyond demonstration areas. Research on tropical forest resources needs to be more interdisciplinary and more closely related to technology implementation.

Much work remains to develop profitable technologies that can supply local people's needs while simultaneously sustaining forest productivity. New techniques need to be based on improved understanding of the biological, economic, and cultural factors affecting forest resources. This calls for interdisciplinary research based on an adequate understanding of the needs of technology implementors.

Options

Initially, Congress could conduct hearings to determine whether the research organizations that receive U.S. funds give adequate priority to interdisciplinary tropical forestry that links research and development. Special attention should be paid to disseminating research results. Congress could increase support for agencies where such research and development is stressed.

The other approaches would be for Congress to appropriate funds specifically to support UNESCO's MAB program or to amend the Foreign Assistance Act to include funds for the

United Nations University. Both promote interdisciplinary research. Additionally, Congress could amend the existing legislation that allocates funds for tropical agriculture to include tropical forestry and agroforestry explicitly. Congress also could determine the feasibility of establishing a forestry research program at existing Consultative Group on International Agricultural Research (CGIAR) institutions. Congress could establish a trust fund for the Forestry Department of FAO of the United Nations specifically to support improved communication among researchers and technology implementors.

Issue (Market Development)

In many areas sustaining tropical forest resources will depend on local markets for forest products. People seldom attempt to sustain the productivity of natural resources used for subsistence products because these appear to be "free." Government agencies typically are not aware of the natural forest's potential to support rural communities.

Tropical forest ecosystems house complex associations of vegetation, wildlife, and other potential resources that could be developed. Development of markets, along with research on ways to manage the unused resources for sustained yields, could help motivate local people and local resource agencies to manage the forests effectively. It could be possible in some places to maintain biological diversity and simultaneously support profitable rural development. However, such market development is likely to reduce subsistence opportunities for landless poor people.

Options

Congress could direct and fund the U.S. Forest Products Laboratory to develop new products and market information to use tropical tree species and increase its efforts to transfer technologies. Similarly, AID could be directed to expand its support for synthesis and dissemination of information on underused tropical forest resources and to assist in developing markets for those products that can be produced on a sustainable basis.

Protect Biological Diversity

Issue

Benefits from preserving the biological diversity of tropical forests accrue to society as a whole, including future generations in the U.S. and elsewhere, yet the costs are borne by the people of the tropical countries.

Developing new markets and ways of harvesting and using tropical forest species eventually may make it possible to manage natural forests profitably and sustainably. But until the markets and technologies are developed, it is necessary to protect and maintain undisturbed portions of these biologically diverse ecosystems for future generations.

Options

Congress could take two approaches to help maintain biological diversity. First, it could conduct hearings on its recent amendment to the Foreign Assistance Act which directs AID, in concert with other appropriate agencies, to develop a comprehensive U.S. strategy to maintain biological diversity.

Additionally, Congress could support the creation of an international fund to subsidize the establishment and maintenance of tropical parks and protected areas. Money for such a fund could be contributed by a variety of sources, including transfers from existing assistance agencies (e.g., AID, multilateral development banks, and U.N. agencies), increased export taxes and import duties on tropical forest products, and donations from private foundations and multinational corporations.

Expand U.S. Expertise in Tropical Forest Resources

Issue

U.S. tropical forest resource expertise is widely scattered and is not being developed or used effectively.

The United States has recognized expertise (both individuals and organizations) in many resource fields, including reforestation, watershed management, commercial forestry, resource inventory and mapping, resource development planning, and information collection, processing, and dissemination. But only a few of these experts or organizations have the experience or training to apply their skills directly to the increasingly important field of tropical forest resources.

Options

Congress could modify the organic legislation of those U.S. agencies whose actions affect the tropical nations or the U.S. tropical territories to say that tropical forests are valuable renewable resources and to direct each agency to conduct its activities without contributing to the unplanned or unmanaged conversion or degradation of tropical forests. Further, Congress could direct Federal agencies to encourage employees to participate in international assistance efforts under existing laws or it could amend legislation to encourage such interchange. Congress could encourage participation of the U.S. private sector to develop and implement technologies to sustain tropical forest resources. Congress could contribute to the United Nations Associate Experts Program whereby young U.S. professionals can gain field experience in tropical forestry. Congress also could designate U.S. centers of excellence in tropical forest resources to develop and make available U.S. expertise in tropical resource issues.

U.S. TROPICAL FORESTS

Introduction

Less than 1 percent of the world's tropical forests fall under U.S. jurisdiction. These forests are located primarily in Puerto Rico, the U.S. Virgin Islands, Hawaii, and the U.S. western Pacific territories of American Samoa and Micronesia (which includes Guam, the Commonwealth of the Northern Mariana Islands, and the Trust Territory of the Pacific Islands). As Congress becomes more involved in efforts to sustain tropical forest resources worldwide, it has reason to pay particular attention to the tropical forests in territories under its care.

Despite their small total land area, the U.S. tropical forests are important resources to local people and economies: they supply food, fodder, fuel, and employment; reduce erosion; and protect ocean fisheries. Most wood products, however, are imported to these areas. For example, Puerto Rico imported $400 million worth of wood products in 1981. Perhaps the most important value of forests on these tropical islands is regulation of water regimes. For instance, because of deforestation the U.S. Virgin Islands no longer has permanent streams. Most other islands also have experienced problems with water quality and quantity.

Only in Hawaii has forestry been made an integral part of the region's economic development. To protect watershed values, most forested land in Hawaii is classified under conservation zoning which restricts or prohibits conversion to land uses other than forest. Nearly half of Hawaii's designated "commercial forest land" is owned by the State. Since 1962, the Hawaii Department of Land and Natural Resources has followed multiple-use programs for managing water, timber, livestock forage, recreation, and wildlife habitat on these lands. In addition, two of the three programs of the U.S. Forest Service Institute of Pacific Islands Forestry are dedicated to research on Hawaiian forests.

Even though forestry problems still exist in the Hawaiian islands (e.g., the recent dieback of native forests, endangered status of numerous native plants and animals) considerable effort has been made to mitigate these problems. A number of organizations working to sustain tropical forest resources are based in Hawaii, including the Nitrogen-Fixing Tree Association, the Bioenergy Development Corp., the East/West Center, and the College of Tropical Agriculture and Human Resources at the University of Hawaii. These are among the sources of expertise housed in Hawaii that can be applied to the U.S. tropical territories and to the world's tropical forest resources.

Forest resources in the U.S. Caribbean and Pacific tropical territories are not receiving a similar level of attention. The forests have suffered degradation in the past as a result of poor land-use practices. More recently, incentives for local people to undertake and improve agricultural or forestry activities have been reduced by dependence on U.S. Federal income supports and by economic development focusing on industrial growth. This has resulted in a movement away from agriculture and corresponding increases in abandoned agricultural land and unmanaged secondary forests. In many places, runoff and erosion resulting from past forest loss threaten water supplies and coastal marine resources. With forest resource development technologies, much of the productivity of this degraded and abandoned land could be restored to support economic growth.

Although current overexploitation of forest resources is not a problem in most of the territories, the remaining forests are vulnerable as populations and expectations rise. Future problems could be averted, however, if sustainable forest use techniques could be integrated into strategies for regional economic development.

The Caribbean Territories: Puerto Rico and the U.S. Virgin Islands

The Commonwealth of Puerto Rico is the largest contiguous tropical area under U.S. jurisdiction (see fig. 7). At least one-third of its land area is under forest cover—mostly second-growth trees, fruit tree plantations, and shade trees in coffee-growing regions. Because Puerto Rico has a relatively large forest area, a relatively well-developed road system, and secure land tenure, it has significant potential for commercial forestry to supply its domestic economy. About 200,000 acres in Puerto Rico have been identified as suitable for commercial forestry. However, large-scale forestry is hindered by high land prices and a law limiting the acreage that can be owned by an individual or corporation.

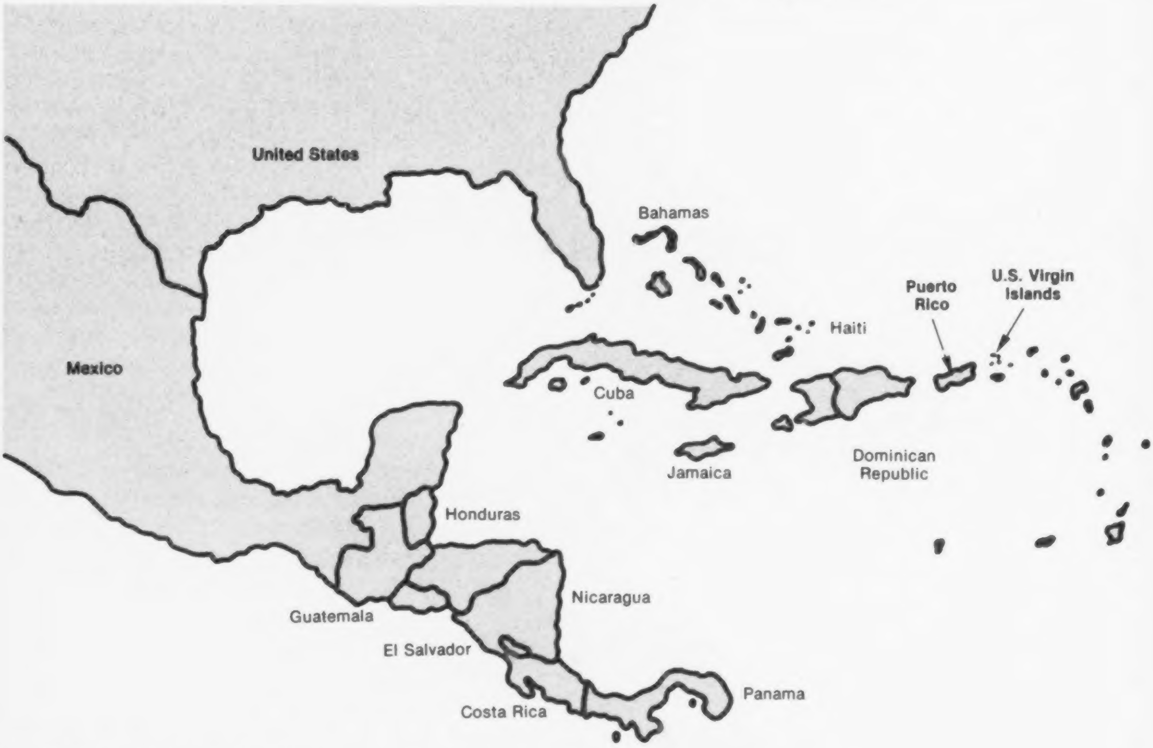
Opportunities exist to develop small-scale forest industries to serve domestic markets using technologies that require comparatively low capital outlay, such as the portable sawmills now used in Puerto Rican Commonwealth forests. The sawmills are one component of a Puerto Rico Department of Natural Resources program to bring private landholders into commercial forestry. This program relies heavily on U.S. Federal cost-sharing programs and on funding from the U.S. Forest Service's State and Private Forestry grants. Increased support for these activities could encourage plantation forestry and increase Puerto Rican self-sufficiency in forest products.

The U.S. Virgin Islands have little remaining forest and no forest industry but are used extensively for tourism. Lack of forest management and a growing population in the U.S. Virgin Islands have disturbed local water regimes. Thus, water must be shipped from Puerto Rico or desalinized from sea water at great expense. Reforestation and management of island watersheds could reduce runoff rates, decrease erosion, and enhance aquifer recharge.

The main constraints to sustaining tropical forest resources in the U.S. Caribbean are lack of support for existing forest resource development institutions and lack of a skilled cadre of local resource managers. The U.S. Forest Service maintains a forestry research station, the Institute of Tropical Forestry (ITF). It also manages the Caribbean National Forest and supports a State and Private Forestry cooperative program with the Puerto Rico Department of Natural Resources and the Virgin Islands Department of Agriculture. At a time when U.S. Forest Service research needs to be expanded to include agroforestry, watershed protection, and other areas of importance to landholders and the public, its research funds and staff size have been reduced.

In the short term, people with general tropical forestry expertise can be attracted to work in the U.S. Caribbean, but in the long term an

Figure 7.—Location of Puerto Rico and the U.S Virgin Islands



SOURCE: Office of Technology Assessment.

established method to train people to manage tropical natural resources specific to that region is needed. Increased environmental education, scholarships, and creation of a natural resource management curriculum at the University of Puerto Rico could help train the necessary resource managers. In the meantime, adequate Federal support of Puerto Rico and U.S. Virgin Islands forestry programs through the State Forestry Grants of the State and Private Forestry Division of the U.S. Forest Service are needed to stimulate development, demonstration, and coordination of desirable forestry practices.

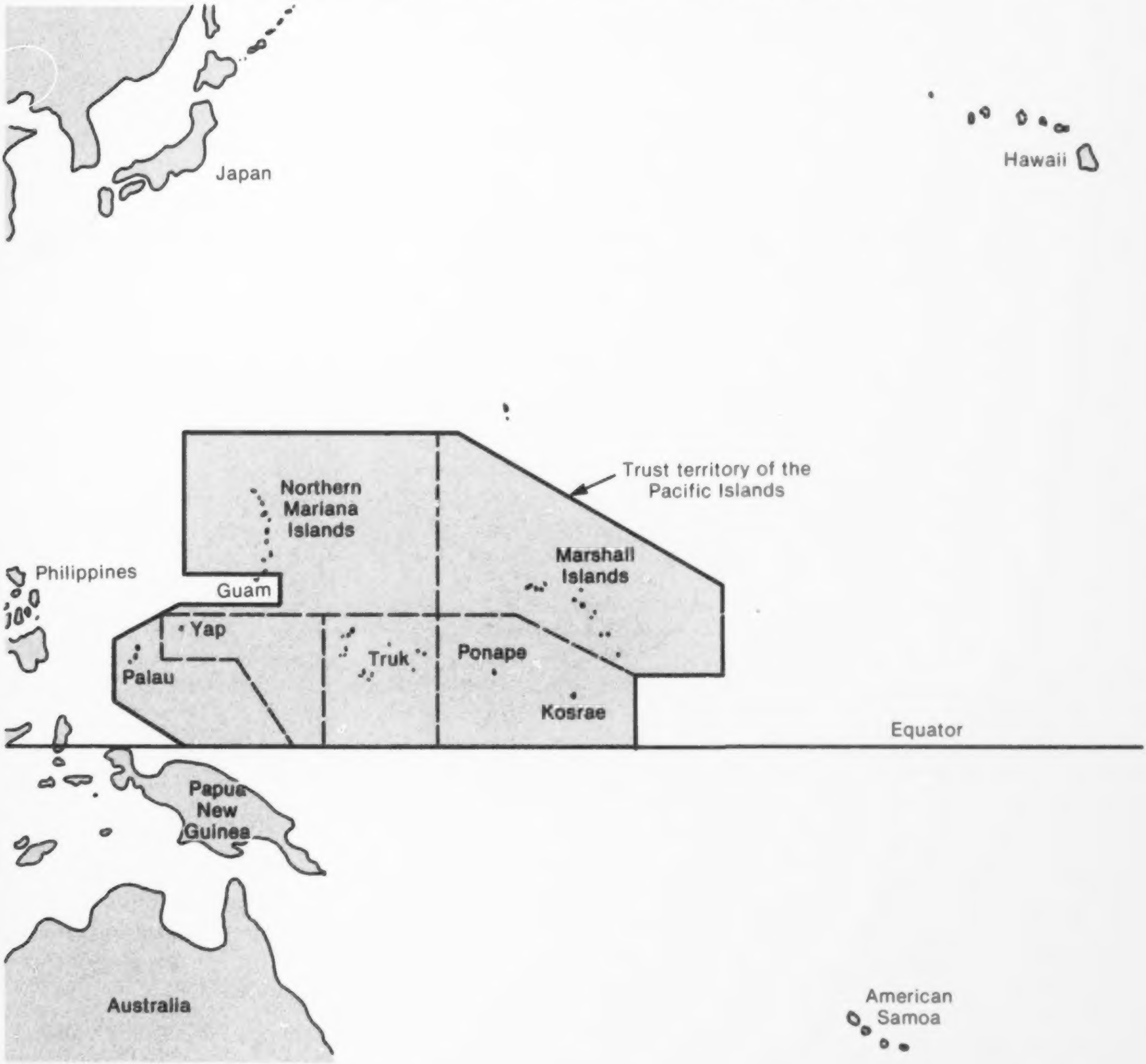
The Western Pacific: Micronesia and American Samoa

U.S. tropical forests exist on some 2,000 islands spread over 3 million square miles in the western Pacific (see fig. 8). Forest cover varies with the nature of each island. Few truly undisturbed forests exist, but considerable areas of secondary forest have regenerated. Little of this is managed to provide forest products. Fuelwood and some nonwood forest products are harvested for local use, but most wood products are imported.

As in the U.S. Caribbean, the major value of forest resources in the U.S. western Pacific is not timber but regulation of water regimes and protection of biologically rich coastal ecosystems. Island people in this region depend heavily for both subsistence and trade on marine organisms that feed and spawn in mangrove habitats, lagoons, and coral reefs. Unplanned exploitation of upland forests can substantially reduce the productivity of these coastal areas. This already is occurring on some islands.

Transportation costs, limited land areas, and insecure or communal land tenure limit the re-

Figure 8.—Location of the U.S. Western Pacific Territories


Japan
Hawaii
Northern Mariana Islands
Trust territory of the Pacific Islands
Philippines
Guam
Marshall Islands
Yap
Palau
Truk
Ponape
Kosrae
Equator
Papua New Guinea
Australia
American Samoa

gion's industrial forestry opportunities. However, small-scale management, harvesting, and processing technologies could be applied to the secondary forests and abandoned coconut plantations to increase their provision of food, fuel, employment, and other goods. For example, improved small-scale charcoal production, if developed and promoted wisely, could increase the importance of wood as a sustainable energy source in the U.S. Pacific. Production from existing agroforestry lands could be enhanced with new techniques. Coconut shell

Photo credit: C. Whitesell

Opportunities exist for small-scale forestry operations oriented toward domestic markets. This small sawmill operates on Ponape, Federated State of Micronesia

charcoal can be used as a filter in various industrial and pharmaceutical uses and could be exported from these islands.

Any forest development in the U.S. western Pacific territories, however, will require careful planning and management to avoid further degradation of the resources and to ensure the sustainable production of both goods and services provided by the forests. This requires up-to-date and comprehensive data bases on tropical forest resources, their uses, and the potentials for their development. U.S. Federal agencies can play a major role in creating these data bases.

Integrating forestry into development planning in the U.S. western Pacific will require personnel with substantial knowledge in tropical resource management and strong local institutions through which they can work. Yet, no natural resource management education programs exist in the U.S. western Pacific territories, and few of the students who receive training at U.S. or other institutions return to work in their own regions. Actions to help supply needed expertise include creating a natural resource management curriculum at the University of Guam and increasing scholarships for potential resource managers.

Additional extension services also could be useful. Developing a group of local, grass roots naturalists with generalized training to assist scientists, spread information on appropriate land uses, and help integrate new technologies with local customs could be a joint undertaking of U.S. and local western Pacific organizations.

Issues and Options for Congress

The primary requirement for sustaining tropical forest resources in the U.S. tropical territories is the development of indigenous organizations capable of managing the islands' resources. Because the territories' governments still depend on U.S. support and their natural resource agencies are generally new, small, and undersupported, the U.S. retains a substantial role in both the development of the resource organizations and in the development and implementation of forest-sustaining technologies.

Option

Congress could direct the U.S. Forest Service to 1) expand the scope of research and technology development in its research institutions with jurisdiction in the U.S. tropical territories and 2) increase cooperative efforts with local governments.

Development of forestry management plans, in the short run, will require technical assistance provided by U.S. expertise. Similarly, adaptation of technologies to conditions in the U.S. tropical territories requires Federal assistance. In the long run Federal aid could be replaced when more people are trained in natural resource management at local institutions. Development of programs to encourage private forestry appropriate for each island probably also will require Federal assistance. The Federal organizations responsible for assisting forestry development in the U.S. tropical territories are too small and their focus is too limited to give the impetus needed for local development. More research, more forestry technology transfer, and greater response to the changing needs of the territories are required.

Option

Congress could support natural resource agencies in U.S. territories by increasing funding for the cooperative State and Private Forestry programs of the U.S. Forest Service institutes in Puerto Rico and Hawaii. Congress could also create a program of grants to territorial governments to encourage investment in privately owned forests.

The Federal Government subsidizes private forestry with cost-sharing and direct payments to forest owners. Replacing these subsidies with a program of grants administered by the territorial governments would provide the flexibility needed to respond to each island territory's unique cultural, economic, and ecological characteristics. Furthermore, it would encourage the development of a constituency concerned with sustaining the forest resources.

PART I
Background

Chapter 2

Importance of Tropical Forests

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Chapter 2

Importance of Tropical Forests

HIGHLIGHTS

- The potentially renewable productivity of tropical forests will become increasingly important over the next 30 years as the tropical nations' population grows from 2 billion to 4 billion people.
- Tropical forests support economic development. They sustain production on land that rapidly loses productivity if they are removed and they can restore the productivity of degraded land.
- Economic development in tropical nations is important to the people of the United States for humanitarian reasons and because of our economic ties with these nations.
- Industrial wood and other forest products earn substantial foreign exchange for tropical nations that trade with the United States.
- Tropical forest resources provide food, fuel, medicines, and other basic human needs for millions of people who live in and near them.
- Where fuel wood is not available, agricultural lands are damaged as people have to burn crop residues and manure that would otherwise be used as fertilizer.
- The highly diverse tropical forests contain plants and animals that have great potential value for medicine, agriculture, and other industries. These will be more valuable as industries come to rely more on biotechnology.

SOCIAL AND ECONOMIC CONTEXT

Tropical nations face a dilemma. Forests must be cut and cleared to increase production in the near term, but the loss of forests can reduce productivity in the long term.

About 76 nations, containing about half the world's population (2 billion), are located entirely or largely within the tropical latitudes (fig. 9). These nations are characterized by fast-growing populations, low per capita incomes, and agrarian economies. Some of their agriculture is subsistence farming in upland areas where soils have low fertility or are dry. Some is commercial agriculture on the more fertile and generally irrigated alluvial plains of major river valleys. The success of both types of agriculture is linked to the status of 1.2 billion hectares (ha) of moist tropical forest and 800 million ha* of drier open woodlands.

Because the population structure in tropical countries is dominated by young people, food and other needs are growing faster than population (fig. 10). For example, food production in developing nations needs to increase by about 4 percent per year, while population is growing at about 2 percent. The age structure also means that population growth has a built-in momentum that will prevent the numbers from stabilizing until well into the next century, if then (80).

Part of the needed gains in agricultural production can come from improved irrigation, crop breeding, and technical inputs that enhance agricultural yields. But average yields probably cannot increase every year by 4 percent. Two percent gains may be possible, but to sustain even that rate over several decades will be very difficult. Consequently, the amount of land farmed and grazed will have to be expanded and people will continue to clear forests to produce food and other goods.

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*This report refers to land area in hectares (ha). One hectare equals 2.47 acres. One square kilometer equals 100 ha. One square mile equals 259 ha. Thus 1.2 billion ha of moist tropical forest is 3 billion acres or 4.6 million square miles.

Figure 9.—Tropical Forests and Woodlands Are Located at Latitudes South of 23.5° N and North of 23.5° S, and at Other Frost-Free Localities

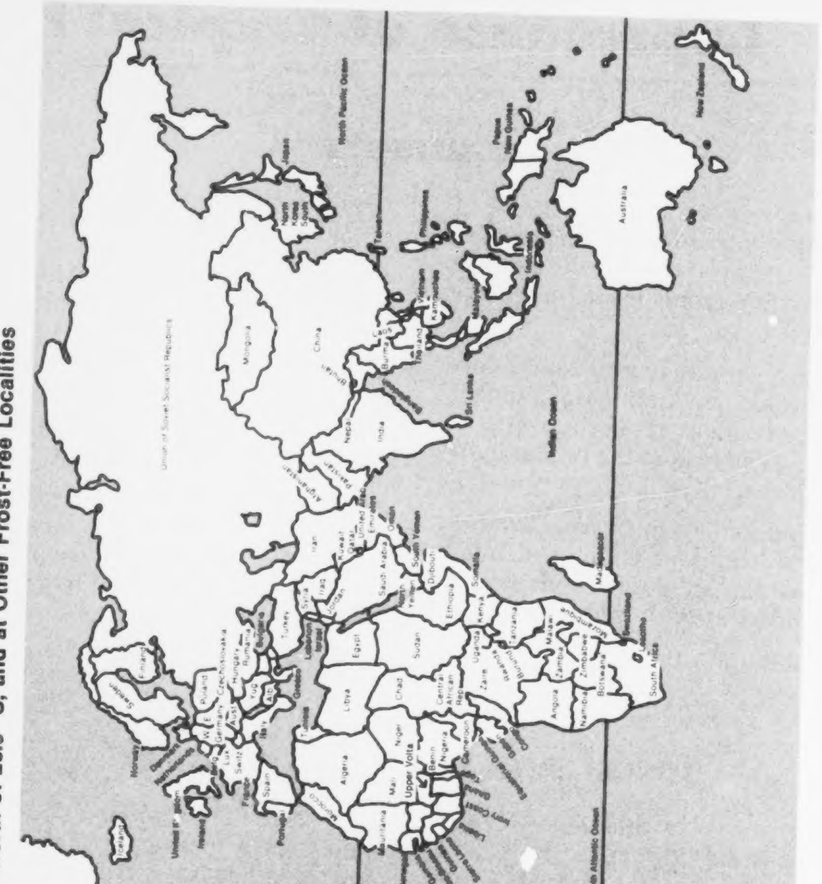
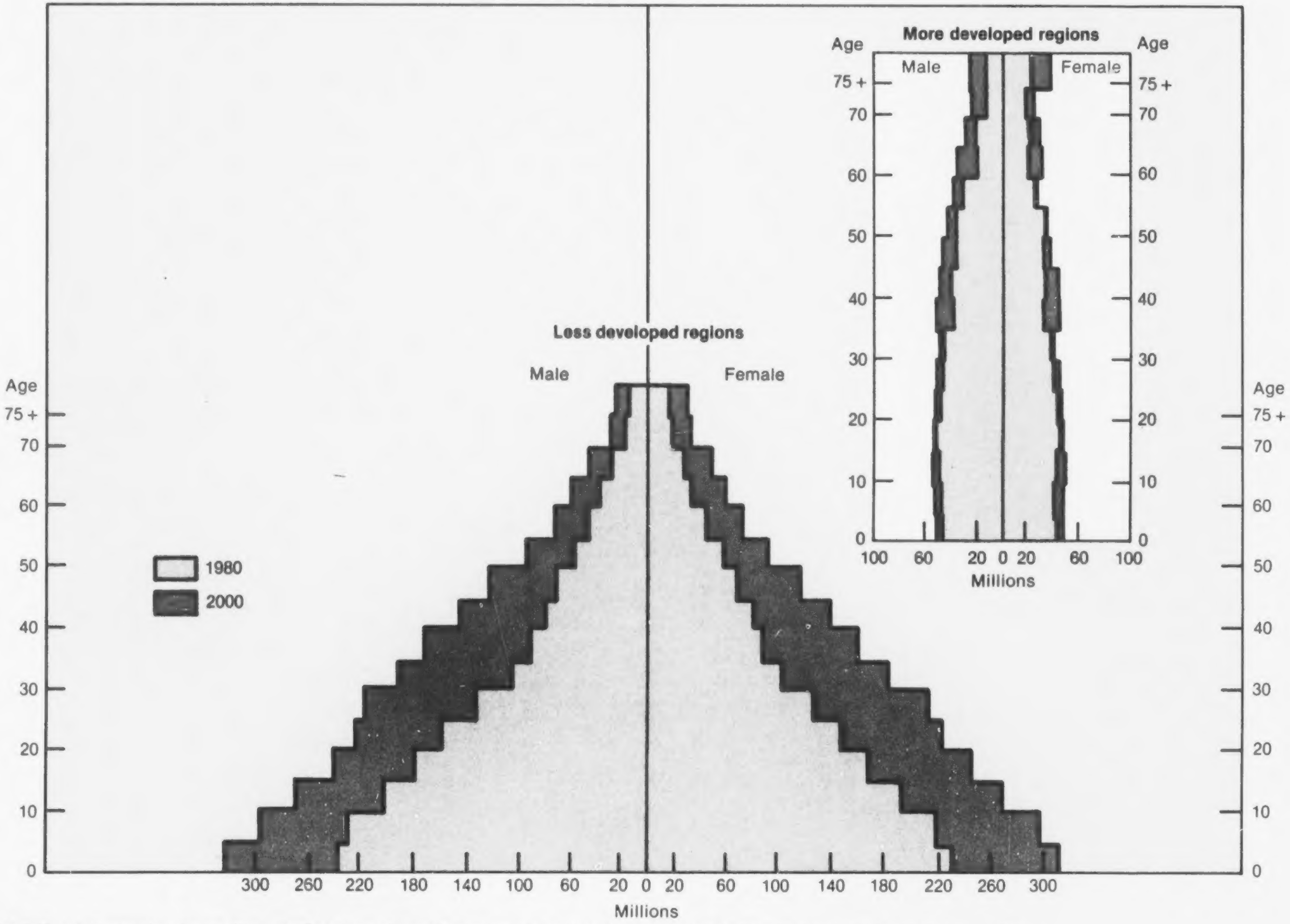

Tropic of Cancer
Tropic of Capricorn
North Atlantic Ocean
South Atlantic Ocean
North Pacific Ocean
South Pacific Ocean
Indian Ocean
Greenland
Canada
United States
Mexico
Cuba
Jamaica
Puerto Rico
Venezuela
Colombia
Ecuador
Peru
Brazil
Bolivia
Paraguay
Uruguay
Argentina
Chile
Iceland
Norway
Sweden
Finland
United Kingdom
Ireland
Denmark
Netherlands
Belgium
Lux
France
Switz
Spain
Portugal
Germany
Poland
Czechoslovakia
Hungary
Aust
Rumania
Bulgaria
Yug
Alb
Italy
Greece
Turkey
Morocco
Algeria
Tunisia
Libya
Egypt
Mauritania
Mali
Niger
Chad
Sudan
Senegal
Upper Volta
Benin
Nigeria
Cameroon
Central African Rep
Ethiopia
Somalia
Djibouti
Kenya
Uganda
Zaire
Rwanda
Burundi
Tanzania
Angola
Zambia
Malawi
Mozambique
Zimbabwe
Namibia
Botswana
South Africa
Lesotho
Swaziland
Madagascar
Syria
Lebanon
Israel
Jordan
Iraq
Iran
Kuwait
Qatar
United Arab Emirates
Saudi Arabia
Oman
North Yemen
South Yemen
Afghanistan
Pakistan
India
Nepal
Bhutan
Bangladesh
Sri Lanka
Union of Soviet Socialist Republics
Mongolia
China
North Korea
South Korea
Japan
Taiwan
Burma
Laos
Thailand
Kampuchea
Vietnam
Philippines
Malaysia
Indonesia
Papua New Guinea
Australia
New Zealand

Figure 10.—Age-Sex Composition of More Developed and Less Developed Regions, 1980 and 2000



SOURCE: U.S. Bureau of the Census, Illustrative Projections of World Populations to the 21st Century. Special Study Series, table 2, pt. B, p. 23, no. 79, January 1979. *In*: U.S. Congress, Office of Technology Assessment, *World Population and Fertility Planning: The Next 20 Years*, OTA-HR-157, February 1982.

Population growth rates and the number of young people in tropical populations also result in a rapidly growing labor force. But in most tropical nations, it does not seem likely that industry and commercial agriculture will be able to sustain growth of over 2 percent per year in job opportunities. Thus, substantial numbers of people will turn to the forests—either clearing them for conventional farming and grazing, or managing them for forestry and agroforestry production.

The need for food and jobs is direct and compelling, while the environmental services provided by tropical forest resources affect tropical people indirectly and forest loss becomes apparent slowly. In the long term, tropical people need the watershed protection, preservation of habitat and genetic diversity provided by the forests (fig. 11).

One approach to accommodate the conflicting needs of tropical people is to accelerate economic development of resources outside the forest to provide food, goods, jobs, and foreign exchange. This would reduce the need to exploit and clear tropical forests. While this may have the greatest effect in the long run, these types of technologies (e.g., improving tropical agriculture) are outside the scope of this assessment.

A second approach is to direct the use of forest resources so that both sets of needs—provision of food, jobs, and national income and maintenance of the forests' environmental services—are fulfilled.

WATER AND CLIMATE

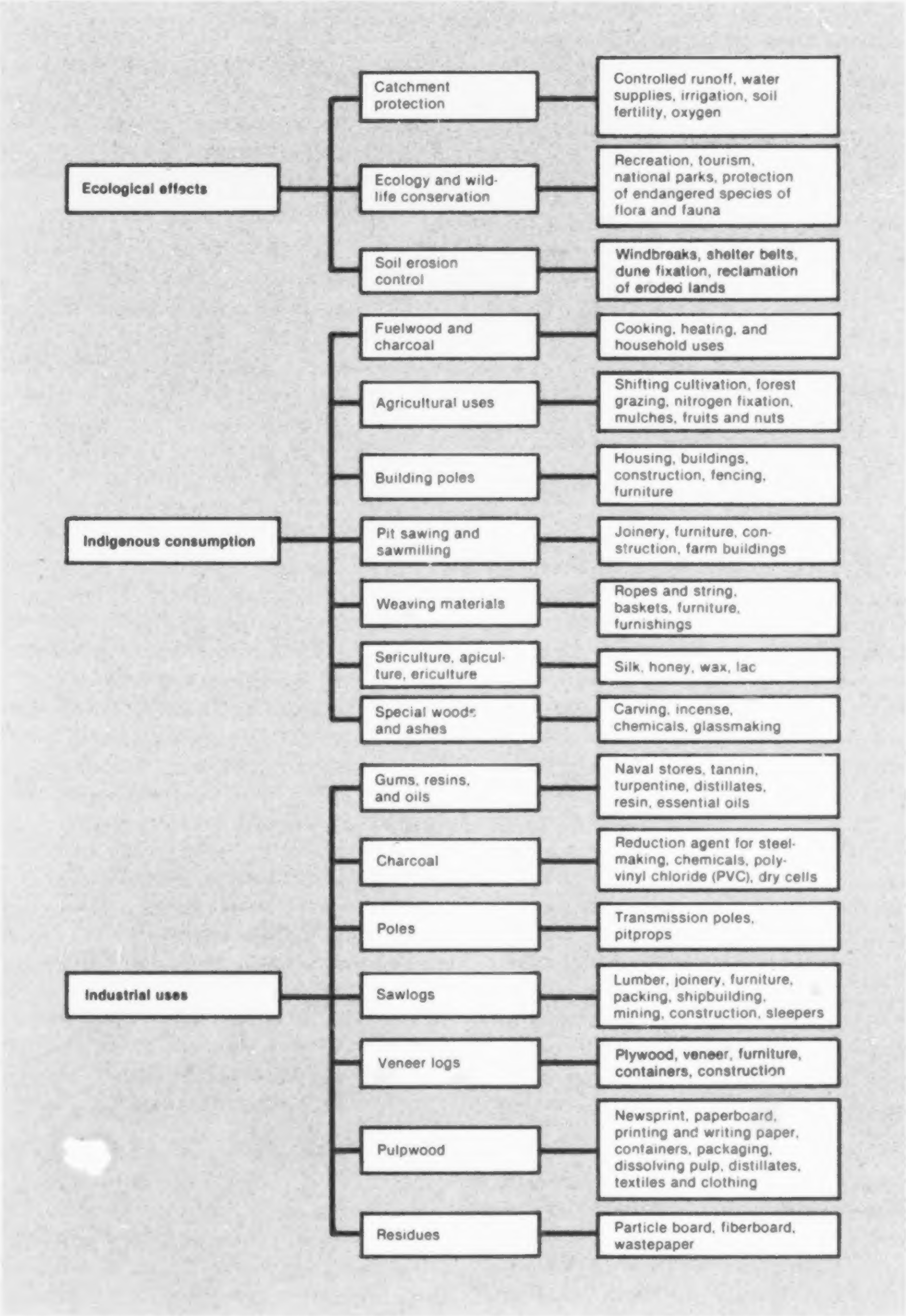
Hydrology in Tropical Regions

Most rainfall in the Tropics occurs where the northeast and southwest trade winds converge. This Inter-Tropical Convergence Zone is intrinsically unstable, oscillating to the north and south of the Equator, causing an erratic rainfall pattern with sharp seasonal contrasts (49). When tropical rains do fall, storms are more violent than those in temperate areas. More water falls per storm, quickly saturating the soil. Consequently, a larger proportion of the rainfall runs off the soil surface. Furthermore, in tropical storms raindrops are larger, thus having great kinetic energy and high erosive power (1,59). For example, in areas of the Amazon Basin where annual rainfall averages 2,100 millimeters per year and land slope is about 15 percent, erosion removes only about 360 kilograms of soil per hectare per year from forested land. But after the forest is cleared, erosion increases 100 times (43).

Tropical forests protect soil and modulate water flows in several ways. The canopy of leaves intercepts rainfall and provides temporary water storage. In addition, organic litter on the soil surface and the porous topsoil store water. The organic litter in closed tropical forests is typically 10 to 30 centimeters thick and the topsoil has a high organic material content (49,61). These mechanisms minimize the impacts of intense rainstorms, reduce peak stormflows, and help mitigate flooding.

The effects of forest cover on streamflow have been measured in tropical regions. In a moist montane forest in Kenya, for example, water measurements were taken on two adjacent 600 ha valleys for over 25 years. When one valley was cleared for a tea plantation—leaving the steeper slopes and riverbanks under forest —the immediate effect was a fourfold increase in peak stormflow. Even after installing conservation practices (e.g., contour planting, cutoff drains, cover crops), stormflows remained double that measured in the undisturbed forest, although the total flows were small (49). Similarly, an experiment was conducted in India on a forest which had been reduced to wasteland by fuelwood cutting and overgrazing. When the severely eroded Siwalik hills of

Figure 11.—The Role of Forests


Ecological effects
Catchment protection
Controlled runoff, water supplies, irrigation, soil fertility, oxygen
Ecology and wild-life conservation
Recreation, tourism, national parks, protection of endangered species of flora and fauna
Soil erosion control
Windbreaks, shelter belts, dune fixation, reclamation of eroded lands
Indigenous consumption
Fuelwood and charcoal
Cooking, heating, and household uses
Agricultural uses
Shifting cultivation, forest grazing, nitrogen fixation, mulches, fruits and nuts
Building poles
Housing, buildings, construction, fencing, furniture
Pit sawing and sawmilling
Joinery, furniture, construction, farm buildings
Weaving materials
Ropes and string, baskets, furniture, furnishings
Sericulture, apiculture, ericulture
Silk, honey, wax, lac
Special woods and ashes
Carving, incense, chemicals, glassmaking
Industrial uses
Gums, resins, and oils
Naval stores, tannin, turpentine, distillates, resin, essential oils
Charcoal
Reduction agent for steel-making, chemicals, polyvinyl chloride (PVC), dry cells
Poles
Transmission poles, pitprops
Sawlogs
Lumber, joinery, furniture, packing, shipbuilding, mining, construction, sleepers
Veneer logs
Plywood, veneer, furniture, containers, construction
Pulpwood
Newsprint, paperboard, printing and writing paper, containers, packaging, dissolving pulp, distillates, textiles and clothing
Residues
Particle board, fiberboard, wastepaper

SOURCE: World Bank, Forestry Sector Policy Paper (Washington, D.C.: World Bank, 1978).

Chandigah were reforested, the peak rate of flow from the watershed was reduced 73 percent and total flow was reduced 28 percent (73).

In dry environments where tree canopies are open, forests are less effective in protecting the soil and modulating water flows, but their influence is still beneficial. Open forests provide shade and act as windbreaks. They reduce soil surface temperatures and wind erosion and stabilize streambanks. They can anchor shifting sand dunes that can otherwise destroy croplands and irrigation systems. In coastal plains, trees can prevent the rise of saline ground water. Trees in arid areas, however, may through evapotranspiration leave less water available for human uses (49).

Local Climate

Tropical forests also can affect local climate. In moist forests with closed canopies, transpiration of water extracted from the soil and the direct evaporation of intercepted rainfall cool the surrounding air. The resulting cooling effect is pronounced, increasing the occurrence and persistence of mists. Thus, the heat flux from a closed tropical forest in the dry season is only half that from similar land covered with subsistence crops or rough pasture (49). Crops cultivated in and near the forest are likely to enjoy greater soil moisture content than those on cleared land, provided that they are planted beyond the root-spread of the trees. Similarly, windbreaks and shade trees can improve microclimates for crops in dry areas.

Some mountain forests in low rainfall areas collect useful amounts of water by condensation from mists and release the water as "drip-fall," sometimes giving rise to perennial streams (49). However, the belief that forests actually cause rain is questionable. (One recent study in the Amazon reports that a significant part of the rain falling there is water evaporated from the forest, but the results have not been verified by other studies.) The dessication that is so frequently a consequence of large-scale forest destruction is due to the hydrological damage caused by loss of infiltration and underground storage. In general, forests thus have a critically important influence on the reception of rainfall, but not on its generation (49).

TROPICAL AGRICULTURE

The populations of tropical nations generally are concentrated on the coastal plains and in the valleys of the great rivers. Most forests in these areas already have been cleared for croplands. Much of this land is irrigated by old systems that control the drainage of seasonal floodwaters. Land that is irrigated with newer systems uses large dams to store excess floodwater and can produce more than one crop per year.

The most productive tropical agriculture is based on annual flooding, but it fails when the floods are severe. New high-yielding crop varieties of the Green Revolution are short-stemmed and so require precise control of water levels. Excessive flooding also can result in shortages of reservoir water for irrigation in the following dry season. Further, the accelerated siltation that accompanies abnormal floods can fill reservoirs, canals, and stream channels, reducing the precision of water control in subsequent years. Thus, the Green Revolution not only increased production from the best tropical croplands but also increased susceptibility to damage by floods and siltation. This makes watershed protection provided by tropical forests even more important.

Unfortunately, recent decades have been a time of rapid deforestation in many tropical nations. Consequently, river flows have become more erratic, flood damage to crops and structures has been severe, and siltation of waterways and reservoirs has increased (49).

The modulating effect of forests on streamflow and the consequences for agriculture are

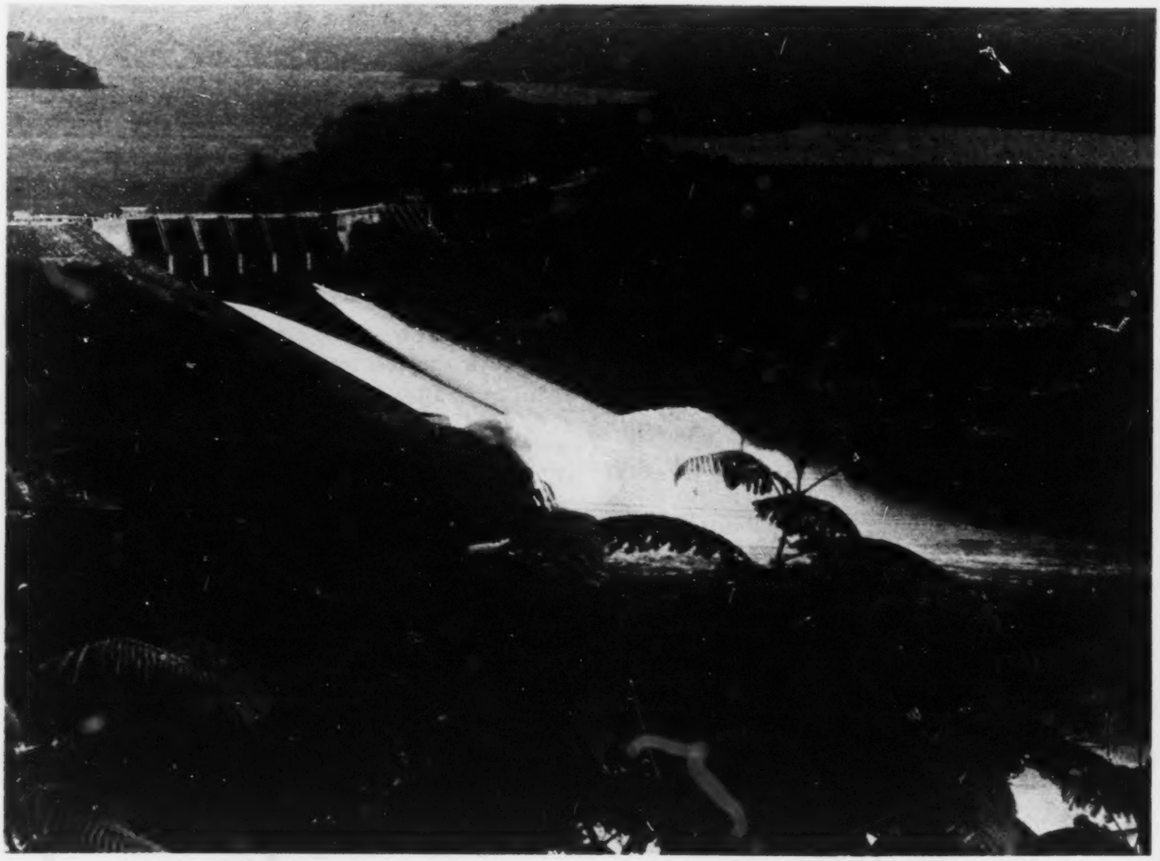


Photo credit: WFP/FAO by Peyton Johnson

Ghana has invested heavily in the Volta River project. The long-term returns on this investment depend on the longevity of the 3,275 mi² reservoir, which in turn depends on watershed protection afforded by forests and agroforestry

most evident when the protective forests have been destroyed. In Pakistan, for example, some 70 million people depend on 14 million ha of irrigated land in the Indus Basin for food. The irrigation depends on river flow, but deforestation on the Indus' headlands has resulted in increased peak flows during the monsoons, followed by water shortages during the dry season. With World Bank funding, two dams, the Mangla and the Tarbella, were constructed for hydropower, flood control, and irrigation. Careful studies of sedimentation rates had indicated that these dams would repay construction costs by providing benefits for many decades. However, parts of both watersheds have suffered uncontrolled deforestation and these reservoirs are filling with sediment at twice the expected rate (49). Similarly, siltation is expected to reduce the lifetime of the Hirakud reservoir in India from 110 years to 35 years (57).

In India, the area of agricultural land damaged each year by floods continues to increase as deforestation occurs. The area of moist forest cleared each year is about 147,000 ha (29), and the area flooded has risen 18 percent over the past 10 years, from 22 million to 26 million ha (72). Clearing of forests over the past 20 years in India has caused flood and erosion damage estimated at U.S.$36 billion in 1982. This estimate includes loss of topsoil, loss of nutrients, loss of property to floods, and shortened reservoir lifetimes (57).

Flood control and irrigation also are important in Central America. By the year 2000, Costa Rica and Panama plan to expand their irrigated areas by 180 percent and 340 percent, respectively (45). Yet, in these countries deforestation is rapid and uncontrolled. In many Central American locations, water needs for irrigation, consumption, industry, and navigation are reaching the limits of low-season flows. Half of the region's forests have been cleared in the past 25 years and water flows are becoming more erratic as deforestation continues (26,45, 77). Similarly, in Africa along a broad belt bordering the equatorial humid tropical forest and along the Gulf of Guinea, the forests are being destroyed. Consequently, several nations in the region are expected to suffer agricultural water shortages before the end of the century (77).

In addition to watershed protection for the current year's crops, forests have longer term values for agriculture. Farmers throughout the world are using more high-yielding crop varieties. In fact, about half the increase in agricultural production in recent decades can be attributed to plant breeding (81). The reliance on high-yielding varieties has reduced the genetic diversity of agricultural systems and so increased the risk of catastrophic damage from diseases, pests, and other stresses. Yet, no great increase in crop failures has occurred. This is due to new methods of crop protection and the ability of crop breeders to respond to threats quickly by breeding new traits into the crops—traits sometimes obtained from wild relatives in the tropical forests. For example, a recent improvement in resistance of peanuts to leafspot was derived from breeding crop varieties with wild forms from the Amazon region. The estimated benefit from this one improvement is $500 million per year (47).

The peanut is just one of many crops with ancestors in tropical forest areas (58). Other cultivated tropical plants include plantains, yams, taro, cassava, sugarcane, potatoes, and cowpeas. Tree crops with tropical forest ancestors and relatives include oil palm, rubber, coffee, cocoa, and many important fruits. These tropical plants account for at least half the calories consumed by people in the Tropics (47), as well as many commodities important to the U.S. economy. Future gains in productivity from breeding these important agricultural crops may depend on the genes in their wild progenitors and, thus, on the continued existence of tropical forests and associated natural areas.

For the people of the Tropics, damage from increased flooding and siltation and the potential loss of crop breeding opportunities mean poorer nutrition, slower economic progress, and less prospect of achieving prosperous, stable economies. For the United States, this means the affected nations are less able to trade internationally. The developing nations already are a major market—and the fastest growing market—for U.S. exports. Their purchases from the United States in 1982 were valued at $82.7 billion, over one-third of all U.S. exports (82).

BASIC HUMAN NEEDS

Wood for Fuel

Wood is the most important source of fuel in most tropical nations (two exceptions are Brazil and Mexico, where oil and gas provide a greater share of total fuel than wood). One and one-half billion people in developing countries meet 90 percent of their energy needs with wood and charcoal. Another billion people meet at least 50 percent of their energy needs this way (25).

Fuelwood, however, is becoming harder and harder to find. Some 100 million people already are experiencing acute fuelwood scarcity and another billion are affected by lesser shortages

Photo credit: R. C. Ghosh

Collecting firewood in the dry, open forests of Madhya Pradesh, India, is arduous labor for women. Because the quantity collected is greater than the annual growth, finding enough wood takes more and more time each year

(30). In some countries, it can take up to 300 person-days of work to satisfy one household's annual fuelwood needs—forcing some dramatic changes in lifestyle. For example, many families in Upper Volta eat only one cooked meal each day, and in Senegal, quick cooking cereal (e.g., rice) has replaced more nutritious, but slower cooking, foods (e.g., millets) (64). Fewer families can avoid the "luxury" of boiling their water (76) and some are forced to keep children out of school to search for wood.

Fuelwood shortages are forcing increasing numbers of people to burn animal dung and agricultural wastes, with adverse impacts on land productivity. It has been estimated that if the cow dung burned for fuel in Asia, Africa, and the Near East were used for fertilizer, grain production could increase by 20 million tons a year (4).

Other Basic Human Needs

The exact number of people living in and near tropical forests, relying on the productivity of forests to supply their basic needs, is not known. The U.N. estimates that about 28 million people practice shifting cultivation in the closed tropical forests of Asia, 20 million in Africa, and 40 million in Latin America—totaling some 88 million people (31). This means some 3 to 4 percent of the total agricultural population in Asia, about 10 percent in Africa, and 35 percent in Latin America, work **inside** the closed forests. These estimates include ethnic populations practicing shifting cultivation as a traditional way of life. They do not include nonagricultural people who are purely hunters and gatherers, nor people who recently moved into forests. This can be significant, since in tropical Asia, at least, squatters probably outnumber shifting cultivators.

Many millions of additional people live in drier, mixed tree and grassland environments (open woodlands). These people are typically livestock herders and dryland farmers; yet, they too are directly dependent on the woodland environment. Their livestock feed on trees and

Photo credit: U.S. Agency for International Development

As fuelwood becomes more scarce, the burning of animal dung increases, depriving the land of nutrients bushes, especially during dry seasons when grasses provide poor fodder. People living in open woodlands use wood for cooking, boiling water, heating, drying crops, and as fuel for small industries. Open woodland dwellers, like the people of the closed forests, use trees and wild plants for medicines, soaps, and many other basic needs (86).

Food from the forests—both closed and open—meets a significant part of the world's nutritional needs. Meat from wild animals, fruits, nuts, honey, insects, fungi, and foliage are all important forest food sources. At least 500 species of edible leaves are used in Africa alone (42). "Bush meat," including rodents and reptiles as well as wild ungulates and other mammals and birds, supply as much as 75 percent of the animal protein consumed in some tropical regions (20).

Forest trees and vegetation are the main materials used in the Tropics to build homes and buildings. In many rural societies, wood frequently is preferred even when other materials are available (91). Local wood also serves as poles, fences, stakes, furniture, tools, and utensils. Substitutes for these products are rarely available in subsistence cultures. Various fibers derived from forest vegetation are also important, especially for household use. Rattans, for example, are climbing palms used for cane furniture, baskets, mats, and similar uses.

In the northwestern Amazon forest alone, at least 1,300 plant species have been used by native people as medicines and drugs (62). Traditional healers in Southeast Asia use some 6,500 plants as treatments for malaria, stomach ulcers, syphilis, and other disorders, and also as sedatives and emetics (50). A number of these plants identified and tested by native people through generations of trial and error yield exceptionally promising compounds when screened in modern laboratories (21,24).

Forests also protect both inland and coastal waters, providing another important benefit to people. After deforestation, increased runoff accelerates erosion and carries excessive amounts of sediment to nearby lakes, reservoirs, and streams. For example, as early as 1904 erosion resulting from deforestation was responsible for clogging the once-navigable Rio das Velhas in Brazil to such an extent that even canoes ran aground (87). Today, deforestation is much more widespread in Brazil, and other navigable rivers such as the Cuiaba and São Francisco have large parts filled with silt from eroded forest soils (3,8). Inland waterway transportation is further damaged by the seasonal drying up of local streams that can be a consequence of deforestation (18,88).

Increased erosion caused by deforestation has accelerated siltation of the Panama Canal's system of reservoirs at the same time that accelerated runoff has diminished water storage in the Canal's watershed. During a 1977 drought, the canal was closed to large vessels because of low water, a situation that experts believe may occur with increasing frequency unless watershed forest cover is restored (85).

Another impact of deforestation on tropical waterways relates to the release of nutrients from the forest biomass and soil. Organic matter production is sharply reduced under nonforest conditions. Further, the soluble nutrients from the ash of burned forests and from rapidly decomposing soil organic matter are easily leached from soil by heavy rainfall. The resulting increased nutrient content of runoff can accelerate the growth of noxious plants and algae in nearby lakes, canals, and rivers. Aquatic weeds block canals and pumps in irrigation projects. Also, they interfere with hydroelectric production, waste water through evapotranspiration, hinder boat traffic, increase waterborne disease, interfere with fishing and fish culture, and clog rivers and canals so that drainage is severely retarded and floods result.

In India, for example, plants reduce water flow in some large irrigation projects by as much as four-fifths. Rafts of water hyacinth weighing as much as 300 tons float over rice paddies in Bangladesh during floods. When the water recedes, the weeds settle and kill the germinating rice. Maintaining forested watersheds would reduce erosion and runoff, reduce populations of aquatic weeds, and reduce the cost of maintaining waterways.

Forests also act as a buffer against the force of typhoons and other violent storms in coastal zones. Tropical Asia, for example, suffers an average of 57 typhoons each year, causing storm damage that averages $2.8 billion (92). Forests reduce the destructive energy of these storms by deflecting wind and reducing the occurrence of landslides and other environmental damage.

Tropical storms are most violent in coastal areas, typically the areas that are most populated. Yet coastal forests are being eliminated more rapidly than most other types of tropical forests, with sometimes devastating effects (45). For example, Bangladesh has a coastal zone of 20,000 square kilometers that supports 20 million people. This nation's coastal areas were extensively cleared in the 1960's, leaving little protective forest. When a severe typhoon struck in 1970, 150,000 Bangladeshis drowned (35,65). Each year, typhoons and floods together claim the lives of 200,000 people and destroy many hundred thousand hectares of crops (92). A portion of these lives and crops could be saved if forest cover were maintained and enhanced (45).

About 15.5 million ha of mangrove forests grow along coastlines and in estuaries in tropical America, Asia, and Africa (31). These forests have several important functions aside from acting as a coastal buffer against storms, seawash, and floods. They also process sewage, absorb nutrients and heavy metals, and precipitate sediments. Most importantly, they provide ideal breeding and nursery grounds for various fish, molluscs, and crustaceans. Many valuable shrimp species breed at sea, after which the young move into mangroves where they seek food and protection. Mangroves also provide nurseries for such commercially important fishes as mullet, grunts, and milkfish (66).

Employment

Forest management and forest products industries can be a major source of employment in tropical countries. Industrial wood harvest in tropical forests takes about 60 person-days per hectare. Planting trees takes even more labor because site preparation usually involves more cutting and tree removal than does harvest (63). Table 2 is a summary of estimated annual person-day requirements for various forest plantation operations in World Bank projects.

Some tropical governments view tree planting as a way to reduce unemployment (33). For example, planting programs are planned with employment as a major benefit in various areas of Brazil. In the states of Minas Gerais and Espirito Santo, a large work force plants 100,000 ha/yr by hand, and in the Amazon region two large companies only do hand-planting. Similarly, large-scale, labor-intensive programs have been developed in Colombia, Venezuela, the Philippines, the Republic of Congo, and other Asian and African countries, and smaller programs are under way in Guatemala and Honduras (89).

Forestry and agroforestry require protection and management and so provide even more employment opportunities. Using agroforestry systems including cultivated crops, several tree crops, and livestock on a 100-ha farm in India, employment is estimated to rise from 20 to 50 people at the final, sustained yield stage. Thus, agroforestry systems to reclaim 5 million ha of India's degraded lands might employ 2 million people (57). Furthermore, forest products could serve as the basis for cottage industries, providing more employment and producing goods for domestic use and export.

Table 2.—Estimated Annual Person-day Requirements for Various Forestry Operations

Plantation design
Spacing: 600-2,000 trees per hectare (ha)
(more for energy plantations)

Task	Person-days
Nursery work/1,000 plants	7-13
Land clearing and burning/ha[a]	10-50
Pitting for planting/ha	3-15
Weeding/ha/yr[a]	6-36
Pruning/ha	5-15
Thinning	8-11

[a] These measures vary greatly according to site conditions.

SOURCE: P.J. Wood, J. Burley, and A. Grainger, "Technologies and Technology Systems for Reforestation of Degraded Tropical Lands," OTA commissioned paper, 1982.

Mangroves

Mangrove forests are important—economically and ecologically. However, mangrove ecosystems can be damaged by human activity. Deforestation of watershed areas can accelerate deposition of sand, silt, and clay in alluvial areas; changes in the pattern and volume of freshwater runoff can be attributed to irrigation, roadbuilding, and other such projects; coastal engineering practices may bring about a change in tidal flushing regimes. Other major stresses include pollutants such as pesticides and insecticides used in large agricultural projects and recurring oil spills due to the exploitation and transportation of offshore oil.

Several mangrove species are highly valued as firewood because they burn evenly with little smoke, and as charcoal because they have high caloric value. Charcoal for commercial sale is the main mangrove product in several Asian countries. Mangrove poles are used extensively for rural houses, foundations, and scaffolding of urban construction because the wood of many mangrove species is durable and resistant to termites (14). In recent years, mangrove has been harvested for woodchips to be used in chipboard manufacture, newspaper, and as a source of cellulose for rayon (71). The conversion of mangrove land to aquaculture ponds also is increasing, which could have potential to increase fish production. However, improper site selection and poor design could have substantial negative impacts.

Management of mangrove forests can be complicated. In clearcut mangrove areas, increased temperatures and evaporation can raise soil salinity so that mangroves are unable to regrow. Hand planting of seedlings is possible but costly. Selective felling systems that retain trees below certain diameters often involve rather complicated regulations that may be difficult to administer. Natural regeneration can be enhanced by clearcutting narrow strips so that nearby trees can provide seeds.

The pressure to clear additional mangrove forest areas for agricultural, industrial, and aquacultural purposes will continue and the demand for fuelwood and poles will increase. Short- and long-term socioeconomic impacts of all alternative uses of mangrove forest areas must be evaluated to determine the optimum uses. It is only partly known, for instance, to what extent marine species are affected by removal of mangrove forests. Improved understanding of this important interaction could have significant forest management payoffs.

COMMERCIAL FOREST PRODUCTS

Wood

The principal commercial products of tropical forests are timber and fuelwood. Tropical hardwoods are used to produce lumber for construction, poles, pilings, railway ties, props in mines, and panel products such as plywood, veneer, fiberboard, and particle board. Hardwood is also important for finished goods such as furniture and paper products. In addition, some softwoods from tropical forests are used for lumber and pulp.

Most tropical forest wood is used within the country of origin and the economic value of this domestic consumption is difficult to assess. Value estimates exist for the 6 percent of the commercial tropical wood harvest that is exported. The total value of wood and wood product exports from the tropical nations has increased by about 500 percent in the past 10 years (32). Indonesia's wood exports in 1980 earned some $1.9 billion. The value of wood exports for Malaysia was $2 billion in 1980; for the Philippines, $415 million; for Brazil, $816 million; for the Ivory Coast, $415 million (32).

World trade in tropical wood is significant to the economies of both the producing and consuming nations. The largest single importer is Japan. Several other large importers—e.g., Singapore, Hong Kong, and South Korea—

reexport most of the wood to industrialized nations after partial or complete processing.

The United States is the second largest importer of tropical wood products and little of this wood is reexported. U.S. hardwood imports in 1978 amounted to $682 million, with tropical countries (principally Southeast Asia) supplying 82 percent of the total. Imports of tropical wood (logs, lumber, plywood, and veneer) averaged $430 million annually from 1974 to 1978. Although the dollar value of these imports seems high, on a volume basis they account for only 1 to 2 percent of all wood used in this country (85). U.S. demand for tropical wood has been growing at rates well above our population and the gross national product growth rates.

Both in the Tropics and in the importing nations, industrial hardwood is used mostly in the housing industry, so industrial demand for tropical wood has grown at a rate that generally follows housing starts. The paper industry is the other major wood user, but it primarily uses softwoods, for which the United States and Canada are major producers. Many tropical nations import paper, and the papermills located in the Tropics still import most of their softwood pulp from the temperate zone. Some tropical nations have begun to use their own natural pine forests, pine plantations, and, in a few cases, hardwoods as a source of pulp. But tropical forests still produce no more than 10 percent of the world's paper and paperboard.

This is likely to change in the next few decades. New technologies, some developed by the U.S. Forest Products Laboratory and U.S. forest industry, make it possible to produce high-quality paper pulp from 100 percent hard-

Photo credit: H. Bollinger

Wood, a major export item for Malaysia, is no longer restricted to sawlogs. Here 8-year-old *Albizia falcataria* trees (a legume species) are harvested for export to the Japanese pulp and paper market woods and from a mixture of many hardwood species (84). International demand for tropical hardwood chips is expected to rise substantially as the new technologies are installed in papermills in wood-scarce Japan and in Europe, where wood shortages are anticipated. Japan already uses hardwood chips for over half of its pulpwood needs (46).

Demand for hardwoods for paper production also will increase within those tropical nations that have growing economies. As income increases, demand for paper products rises rapidly among relatively poor consumers as long as wood supplies are abundant (17).

Fuelwood and charcoal enter commerce for both household use and industry. Wood fuels have become much more important for industries in tropical nations since the rapid rise in fossil fuel costs. Wood is the least expensive energy source available for many cottage industries and charcoal the highest quality local source for some uses. For example, Brazil has 1.5 million ha of eucalyptus plantations established to supply charcoal to the iron and steel industry in the state of Minas Gerais (31).

The Philippine Government is planning two large wood-consuming industrial facilities in the province of Ilocos Norte. The first of a number of 3-megawatt "dendrothermal" electric powerplants dependent on wood from fast-growing trees as boiler fuel is under construction. Another project that will involve two large pig-iron blast furnaces and will rely on charcoal from local wood is being planned (36).

Products for Medicine

The importance of the tropical forests, especially the moist forests, as a source for medicines is largely a result of their high biological diversity. Some of these forests contain communities of species that have existed for 60 million years, making them the oldest continuously established land ecosystems known. Their great age and ecological stability have allowed evolution to proceed in a relatively undisturbed manner, and it is probably due to this stable history that tropical moist forests developed their extreme biological richness (45).

Because tropical moist forests contain so many species, each species must compete with and defend itself against many potential enemies, and one way to do this is by developing alliances (e.g., symbiosis) with other species. Thus, tropical forest species are highly interactive. The millions of plant and animal species also have had time to develop complex chemicals that help them interact with other species. It is because of these "biologically active" chemicals that the tropical forests are considered Earth's richest storehouses of potential drugs.

Today, medical science is highly dependent on chemicals produced naturally by plants. One-fourth of all U.S. prescriptions contain ingredients from higher plants (27). In 1974, the United States imported $24.4 million worth of medicinal plants to produce about $3 billion worth of drugs. The commercial value of these products is over $8 billion per year. When nonprescription items are included, the value doubles (28).

Although chemical screening has been done on less than 1 percent of the tropical species, already some 260 South American plants have been identified as having potential for fertility control. Some 1,400 tropical forest species are believed to have anticancer properties (7,16, 21,68,70). The National Cancer Institute has screened about 35,000 higher plant species for activity against cancer. As of 1977, about 3,000 of these had demonstrated reproducible activity and a smaller number were appropriate for clinical trials (23). Rotenoids from the roots of tropical trees, for example, are being tested clinically in the United States as antitumor drugs.

One tropical plant, the rosy periwinkle, has had a profound effect on treatment of leukemia. In 1960, people suffering this disease faced one chance in five of remission. But because of two drugs developed from the rosy periwinkle, the chances of remission are now four in five (41). *Tabebuia serratifolia, Jacaranda caucana,* and *Croton tiglium* are tropical trees, and each produces a unique anti-cancer compound whose effectiveness has been proved in the laboratory (51).

Tropical forest plants are significant in treating other medical problems, notably hypertension (2,41,44,67). D-tubocurasine, made from the South American vine *Chondrodendron tomentosum*, is widely used as a muscle relaxant in surgery in the United States. Chemists have been unable to produce it synthetically in a form having all of the characteristics of the natural product (52). The drug's supply, therefore, continues to rely on extracts from wild plants.

Tropical forest animals are also necessary to medical science. Primates are the most important group. They are used widely in medical research and pharmaceutical trials.[1] Tropical primates are especially important because of their similarity to humans. For example, research into malaria, cardiovascular diseases, cancers, hepatitis, and other diseases commonly uses rhesus monkeys, longtail macaques, squirrel monkeys, chimpanzees, African green monkeys, and owl monkeys.

Some 34,000 primates were imported into the United States in 1977 for drug safety tests and drug production (5). Virus-free polio vaccine perhaps is the most important of the drugs produced this way, using many thousands of tropical forest African green monkeys. The Central and South American owl monkey is the only known nonhuman animal suitable for malaria chemotherapy and immunology studies (5). Few of these important animals are raised in captivity; most are captured, and they are becoming scarce as their forest habitat is being destroyed.

Other Forest Products

Tropical forests provide a broad array of nonwood products.[2] Some are produced in plantations of selected tree species. Others are gathered in natural forests and brought to market through a diffuse system of collectors and middlemen. These are often called "minor forest products," although their importance frequently is greater than that term implies. For example, tropical forests provide essential oils, exudates, gums, latexes, resins, tannins, sterols, waxes, esters, acids, phenols, alcohols, edible oils, rattans, bamboos, flavorings, sweeteners, spices, balsams, pesticides, and dyestuffs.

Few nations have collected data on the commercial value of these nonwood forest products. One exception is India, where nonwood forest products are worth about $135 million per year, equivalent to one-fifth of the value of industrial timber (48,69). Indian forests also produce a substantial quantity of animals used for food, scientific research, and other purposes. In Indonesia, rattans generate an export trade worth up to $5 million per year. The world trade in rattan end products now totals $1.5 billion (22,37).

World trade in essential oils and spices from tropical forest plants, such as camphor, cassia, cardamon, citronella, and cinnamon, exceeds $1 billion per year. The United States now imports about 10,000 tons per year of these kinds of oils and spices, with a value of over $100 million (24,54,55). A systematic investigation of the many nonwood forest products used by the forest-dwelling people of the Tropics might lead to increased use of these materials and further enhance the economic importance of the forests.

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[1] See ongoing OTA assessment "Alternatives to Animal Use in Testing and Experimentation."

[2] See *Workshop Proceedings on Plants: The Potentials for Extracting Protein, Medicines, and Other Useful Chemicals* (Washington, D.C.: U.S. Congress, Office of Technology Assessment, OTA-BP-F-23, September 1983), for additional information.

ENVIRONMENT

Endangered Species

Tropical habitats contain a significant number of the world's endangered species. As discussed earlier, tropical moist forests are both the most biologically complex and species-diverse* biome on Earth. The complexity is both dynamic (highly interactive) and stable (able to maintain itself for long periods). Yet the stability depends on an important provision—that external forces do not exceed certain critical thresholds. Human intervention may easily exceed these thresholds.

Because of geographic confinements and specialized ecological requirements, tropical moist forest species are unusually susceptible to extinction (46). Many species are found in only one small area, so even a limited amount of deforestation can exterminate entire species. Further, species are highly interdependent. For example, Brazil nuts are probably the most commercially significant food gathered from forests. The nuts will grow only where a particular type of bee lives, as only this bee can pollinate Brazil nut flowers. The bee, in turn, lives only where a particular type of orchid is found, because it must obtain a chemical from the orchid to attract its mate. Thus, the tree has not been domesticated away from the forest where the bees and the orchids are found. Further, for some of the nuts to serve as seeds, the nuts must be chewed by a rodent to soften the fruit, allowing seed germination. Thus, Brazil nut tree reserves must be large enough to support a breeding population of this rodent. Such complex systems of interdependence are another reason why entire species can be threatened by small changes (75).

At least three-quarters of the projected extinctions worldwide until the end of the century are expected to occur in tropical moist forests. Degradation and destruction of tropical forests and woodlands could precipitate a fundamental shift in the course of evolution (45). Of more certain concern is the loss of potential resources, not only chemicals and animals that may be used directly in medicine, agriculture, and other industries but also genetic information with great potential for biotechnology development.

Migratory Animals

Tropical forests provide habitats for many of the world's migratory and endangered species. About two-thirds of the birds that breed in North America migrate to Latin America or the Caribbean for winter (74). In general, forest habitats are more important for migratory species than was previously thought. Many migratory species winter in tropical highlands—areas that have been rapidly preempted for agriculture. Since migratory species concentrate often in smaller areas in winter, the effects of clearing 1 ha of forest in Mexico probably are equivalent to clearing 5 ha in the Northeastern United States (74).

Migratory species have economic, environmental, and esthetic values in the United States. For instance, some migratory birds play an important role in integrated pest management systems for agriculture in the Eastern United States, yet they could become more scarce as their wintering grounds in the Tropics are lost to deforestation.

Climate

The question of whether tropical deforestation can disrupt the stability of world climates is highly controversial. The scientific understanding of the climate effects of deforestation is still theoretical. When forests are removed, more solar heat is reflected back into space (the "albedo" effect). Some scientists believe that this can lead to changes in global patterns of air circulation, with potential impacts on agriculture (53,60).

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*Biological diversity includes two related concepts, genetic diversity and ecological diversity. Genetic diversity is the amount of genetic variability among individuals in a single species, whether the species exists as a single interbreeding group or as a number of populations, strains, breeds, races, or subspecies. Ecological diversity (species richness) is the number of species in a community of organisms. Both kinds of diversity are fundamental to the functioning of ecological systems (17).

Another effect of forests on global climate is their role as a carbon reservoir in the carbon cycle. As large areas of forest are converted to nonforest, the carbon that had been stored in wood and in organic material in the topsoil is released to the atmosphere as carbon dioxide. When croplands, grasslands, or degraded brush replace moist forest, the new vegetation stores much less carbon. Thus, net annual deforestation adds carbon dioxide to the atmosphere (90).

The concentration of carbon dioxide in the atmosphere has been increasing for several decades, apparently more from burning fossil fuels than from deforestation. Scientists agree that continued increases in atmospheric carbon dioxide will produce a "greenhouse effect" leading to a global warming trend. Doubling of the atmospheric carbon dioxide would probably raise the average global climate by several degrees centigrade. Some scientists hypothesize that increased cloud cover and other environmental change will confound the greenhouse effect. The effects of such trends on agriculture or on the world's hydrological systems are unknown. Likewise, the role of the world's forests and the effect of substantial deforestation are still uncertain. Some scientists consider deforestation to be a significant factor in the concentration of atmospheric carbon dioxide, while others do not (10,12,15,19, 34,90).

POLITICAL IMPLICATIONS

Stability of the renewable natural resource base in tropical countries affects both the economic viability of U.S. investments overseas and the political stability of the host nations. Foreign assistance projects funded by the U.S. Government and development projects funded by the U.S. private sector are being undercut by flooding, siltation of reservoirs, pest outbreaks, and other problems associated with deforestation. For example, the reservoirs used to operate the Panama Canal are rapidly filling with silt (85), as are hydroelectric reservoirs in Pakistan, Thailand, the Philippines, Indonesia, and many other nations (49).

Food and jobs are critical for political stability in developing nations and both are reduced by inappropriate deforestation. Food supplies and employment can be increased in the long run, however, by reforestation of degraded land and by forest management. Frontiers of human settlement, with relatively untapped supplies of natural resources, historically are a source of new employment opportunities. Today, however, the remaining frontiers are mostly infertile or dry lands unable to support large numbers of people using current technologies. Thus, many rural unemployed persons migrate to the cities. As unemployment climbs, changes in the distribution of income within societies further aggravate social inequities and political stresses (11).

One consequence of the inability of developing country governments to create sufficient jobs is that people emigrate to countries with slower population growth and greater per capita resources. The flow of refugees from Haiti to Florida is sometimes cited as an example of the economic and social disruption caused, in part, by tropical deforestation and consequent environmental deterioration (9).

IMPORTANCE TO FUTURE GENERATIONS

Tropical forests have particular importance to future generations. With few exceptions present agriculture systems cannot accomplish sustained productivity on infertile or dry sites without expensive inputs of irrigation water or fertilizers. But scientific study of natural ecosystems, in concert with applied research to develop technologies, possibly can discover how sustainable agriculture can be achieved on this land. Such research has hardly begun and it is a slow process. Thus, the tropical forests serve future generations by the information they reveal to science and by maintaining the quality of the land until sustainable systems for more intensive use are developed.

The Tropics are thought to be the repository of two-thirds of the world's approximately 4.5 million plant and animal species, only about 500,000 of which have been named. That means that about 2.5 million of the tropical species are yet unknown to science (58).* These unknown species are resources of incalculable importance for the future. Undoubtedly, new sources of food, drugs, fuel, and products lie undiscovered in tropical forests.

Although vertebrates are generally thought to be well known on a worldwide basis, only about 60 percent of the estimated 5,000 species of fish in the fresh waters of South America have been scientifically described and named, even though these comprise a large proportion of the diet of local people. A principal source of meat for Paraguayan farmers is a peccary, made known scientifically only in 1977 (58).

Tropical forests offer potential resources for plant breeding, genetic engineering, and other biotechnologies. Because farming environments are constantly changing as pests or plant diseases threaten or as weather changes, agriculture relies on the continued input of genetic diversity for plant improvement. Germplasm is the resource to which plant breeders turn for desirable characteristics—resistance to pests or stress, or improved growth qualities. A Peruvian species, for example, contributed "ripe rot" resistance to American pepper plants and a wild melon in India was the source of resistance to powdery mildew that threatened destruction of California's melon crop (47). A wild relative of the potato from Peru has been known for decades to be highly resistant to insects because of sticky hairs on its leaves, but this resistance has not been useful to agriculture because the wild plant cannot be crossed with domesticated kinds of potatoes. Now the sticky-hair characteristic is expected to be transferred with new biotechnology methods. If it works, the result could be new potato strains that have a much reduced need for pesticide applications. This implies substantial gains in production of this important food and attendant environmental benefits from reduced insecticide use. It is not possible to predict with accuracy what germ plasm will be needed in the future.

With the gradual consumption of fossil fuels and other nonrenewable resources, the United States and other nations are expected to turn increasingly to biological systems for industrial and chemical feedstocks and for solutions to pollution and other environmental problems (78,79). Some complex chemicals and some more simple biological processes can be invented in the laboratory, but most have to be found in nature.

Genetic materials and basic systems found in nature can be reproduced or adapted with bioengineering techniques. New techniques for cloning plants and micro-organisms already are enabling laboratory biologists to screen existing organisms for their production of useful chemicals much more rapidly and efficiently than in the past. The newly developing techniques for genetic manipulation offer opportunities to adapt existing organisms to new uses (79).

For example, tropical forests have a greater proportion of alkaloid-bearing plants than any other biome (6,39,56). Many of the plant species contain hydrocarbons as well as carbohydrates in their tissues. These plant tissues can be renewable sources for many chemicals, including fuels, now derived from nonrenewable fossil sources (13,38). Since tropical forest species usually are restricted to small geographic areas, opportunities are lost wherever the forests are removed before their unique biota has been identified, screened, and assessed for usefulness (83).

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*No one knows how many species exist. Some estimates put the figure as low as 2 million; many converge on a figure of 5 million to 10 million; if tropical insect species are included, the number could be closer to 30 million (40).

U.S. Stake in Tropical Forests

Political Interests

- The United States has strong commitments to world peace, economic and social stability, and maintenance of the Earth's basic life-support systems, commitments that require concern about the integrity and long-term productivity of the global natural resource base, including the tropical forest component.
- The United States is party to a broad array of international resolutions, strategies, and agreements that call on all participating nations to promote and undertake improved management of the forest resource.
- U.S. public institutions and private firms conduct activities that directly and indirectly affect the forests of other nations and, therefore, are in positions to influence the attitudes and actions of host governments and local citizens toward the United States by their attention or inattention to sound resource management.

Economic Interests

- The non-oil-exporting developing countries purchase one-third of all U.S. exports. Adverse domestic natural resource conditions could seriously affect the ability of these countries to buy U.S. goods and services.
- U.S. economic growth requires a sustained supply of wood and wood products at a reasonable price. The United States will continue to look to imports from tropical countries to help meet the demand for certain hardwood products.
- Sizable U.S. investment in international development assistance programs can be undercut by deforestation-induced problems (i.e., intensified flooding and siltation).
- The world's closed tropical forests contain numerous little-known or undiscovered plant species, many of which are likely to have important uses as food crops, medicines, resins, and other industrial products. Many others are already used for such purposes.

Humanitarian Interests

- The United States is committed to meeting basic needs and supporting economic and social development in the less developed nations of the world which, in turn, is linked inextricably to the quality and integrity of the world's natural resource base. With increasing frequency, development programs are being affected adversely by deforestation-related problems.
- The United States and other nations have raised humanitarian concerns about indigenous populations whose cultures and very existence may be threatened by destruction of the forests.
- The United States increasingly is being requested by governments and international development organizations to provide technical assistance and financial support for forest-related activities in developing countries.

Environmental Interests

- U.S. public institutions have statutory and policy responsibilities to protect and manage wisely the environment and natural resources of our Nation, as well as those of other areas within and outside U.S. jurisdiction in which U.S.-sponsored or U.S.-assisted activities are carried out.
- The United States shares, with South and Central America and the Caribbean area, hundreds of species of migratory animals, including birds, insects, marine turtles, and mammals, whose survival depends to varying degrees on tropical forests.
- The United States is committed to helping preserve the world's flora, fauna, and vulnerable ecosystems by virtue of domestic legislation and national policies, and by being party to a large number of international conventions and agreements. Principal among these measures are the Endangered Species Act of 1973, the Convention on International Trade in Endangered Species of Wild Flora and Fauna, and the Convention on Nature Protection and Wildlife Preservation in the Western Hemisphere.
- Large-scale destruction of the Earth's rain forests runs a risk of triggering global climate change, with uncertain but potentially adverse consequences for world food production and human well-being.

Educational and Scientific Interests

- The influence of tropical forest ecosystems on global physical, biological, and geochemical processes is poorly understood and requires long-term study.
- The unique flora and fauna of the tropical forests continue to provide outstanding scientific and educational opportunities.

SOURCE: U.S. Interagency Task Force, *The World's Tropical Forests: A Policy, Strategy, and Program for the United States*, Department of State Publication 9117, 1980.

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Chapter 3

Status of Tropical Forests

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Chapter 3

Status of Tropical Forests

HIGHLIGHTS

- The area planted with trees in tropical regions each year is only about one-tenth of the forest area cleared.
- Gradual resource degradation, especially in the drier open forest areas, may have a greater long-term impact on human welfare than deforestation.
- Landsat imagery has greatly improved knowledge of closed tropical forests and this is enhancing forest management. However, data on open forests and forest resource degradation are still imprecise.
- Forest data aggregated by region may suggest that no global problem exists. However, country-by-country analyses show that rates of deforestation are high and forest area per capita is already low in many tropical nations.
- The acreage within tropical forests that is fallowed or abandoned is growing rapidly. Some of this will naturally return to forest cover, but most of it does not regain productivity without a concerted reforestation effort.
- Most tropical forest is owned by national or State governments, but locally recognized rights to use the resources greatly complicate management efforts.
- Tropical forestry historically has tended to neglect the basic needs of people who live in and near the forests. This is changing as laws, policies, and forestry professionals' attitudes give more attention to fuelwood, and to relationships between forestry and agriculture.

THE DATA BASE

Data on the extent and condition of tropical forest areas are abundant but widely scattered and frequently inaccurate. Some of this information is based on old, imprecise measurements or estimates that have been updated through simple extrapolation. Accuracy is further impaired by lack of standard definitions and classifications of forest types; thus, the data are difficult to compare across studies. Microlevel studies of project areas or watersheds contain some of the most reliable and detailed information on forest resources and land use, yet this information is hard to obtain because it is poorly distributed.

A comprehensive synthesis of data about the world's tropical forest resources was conducted by the United Nations Food and Agriculture Organization (FAO) with the assistance of the United Nations Environment Programme (UNEP) (3,4). The FAO/UNEP study is the first where the definitions of forest types and conditions are consistent across countries. It covers 76 nations; 73 nations are tropical or partly tropical, and 3 nations are outside the Tropics but are directly influenced by tropical monsoons. It does not include the tropical regions of China, Australia, islands off the coasts of Africa, the Pacific islands, or Puerto Rico. Some of the forests included are in places where the climate is more temperate than tropical.

The FAO/UNEP study relies mainly on data supplied by governments. Most measurements and estimates in various categories of forest were made in the 1970's. Then, using the estimated rates of change from one category to another, the figures were projected to represent the situation in each nation as of 1980.

Several nations did not have complete data, and for 13 of these FAO commissioned new Landsat analyses. Some of the government estimates used by FAO are also based on Landsat data.

Data gathered from the U.S. Landsat program has greatly enhanced the accuracy of information on the extent of forests. By using computers to study Landsat data, investigators can distinguish primary forests from secondary forests, closed forests from open forests and grasslands, and dominant types of trees (e.g., broadleaved, coniferous, mangroves).

Unfortunately, Landsat data have not been collected long enough to reveal trends in the forest cover over time. Hence, only a few of the estimated deforestation rates given in the FAO/UNEP study, presented later in this chapter, are based on remote sensing data. The rest are mainly subjective estimates. In addition, since expertise and computers to analyze Landsat data are not available in some tropical nations, many analyses have relied on visual interpretation of images. This method is more subjective and less sensitive to small-scale changes in forest area boundaries. In some cases, images cannot be used because of cloud cover.

EXTENT OF REMAINING TROPICAL FOREST

Closed Forest

Tropical nations contained some 1.2 billion hectares (ha) of closed forest at the end of 1980. Tropical America has 57 percent of the world's closed tropical forests, while Asia has 25 percent, and Africa has 18 percent (fig. 13). These forests are unevenly distributed among the tropical nations. Brazil alone has nearly two-fifths of the world's total closed tropical forests and Indonesia and Zaire each account for nearly another tenth (table A-1 in app. A).

The condition of closed tropical forests may be divided into several categories: undisturbed, logged, managed, physically unproductive, and protected areas. Table A-2 in appendix A shows the percent of forest in each category for each of the 76 nations.

Over half (56 percent) of the total tropical closed forest is classified as **undisturbed** forest. This forest has commercial potential, but most of it is relatively inaccessible to human populations. When Brazil and Zaire with their enormous remote forests are excluded, the remaining tropical nations have two-fifths (41 percent) of their closed forest in the undisturbed category.

Another 14 percent of the total closed forest is productive forest that has been **logged** but is not under active forestry management. Ivory Coast, Togo, Benin, Sri Lanka, and Belize all have at least 60 percent of their closed forest in this condition. Some other countries have had extensive logging but register little forest in the logged condition because farmers quickly convert the logged forest to temporary or permanent cropland. A prime example is Thailand, which has had extensive logging but shows no forest in the logged condition.

Only about 3 percent of the total closed tropical forest is classified as **managed.** Much of this is in logged-over condition, but significant investments are being made to manage natural regeneration. India classifies 63 percent of its closed forest as managed; Burma and Malaysia each classify about 12 percent as managed. Excluding these three countries, only 0.3 percent of the rest of the tropical closed forest is classified as managed. Most of that is in Ghana, Uganda, Kenya, Sudan, and Zambia.

Another one-quarter (23 percent) of the closed forest is **unproductive for physical reasons**. Much of this has not been disturbed

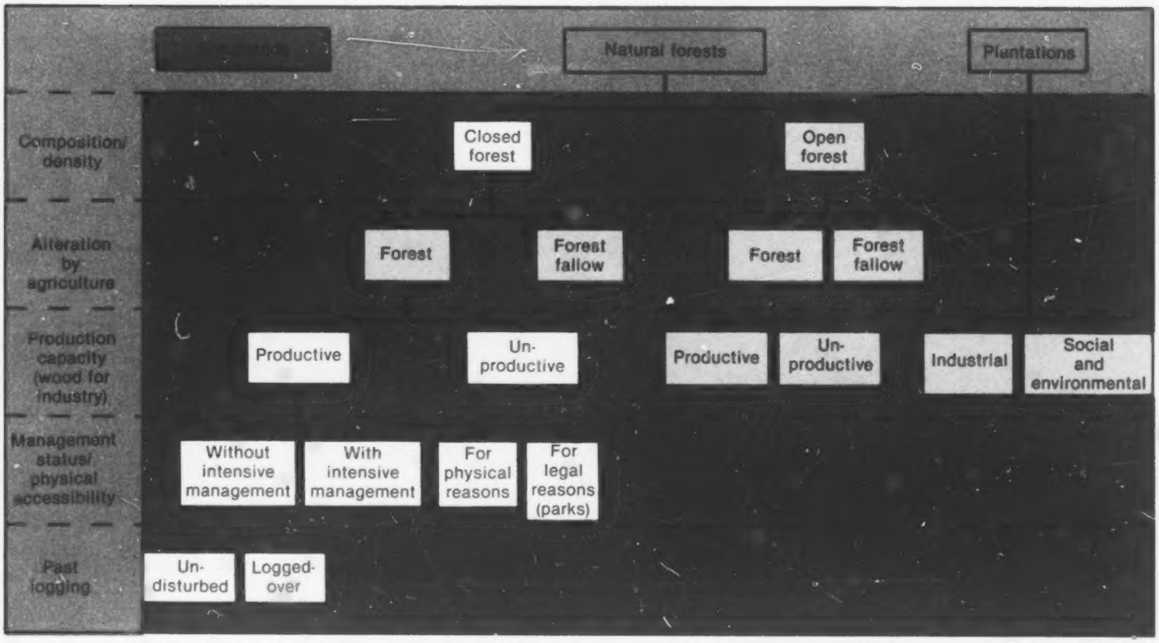
Definitions of Forest Categories

To discuss the status of the world's tropical forest resources, the FAO/UNEP study divides forests into a number of categories (fig. 12). Those used in this report are:

- **Closed forest** includes land where trees shade so much of the ground that a continuous layer of grass cannot grow. The tree cover is often multi-storied. Trees may be evergreen, semideciduous, or deciduous. Closed forests grow where the climate is relatively moist. The data on closed forest areas *do not include the land which is forest fallow*, which is accounted for separately. Forest plantations are also separate.
- **Broadleaf forest** is a subset of closed forest, where broadleaf species (dicotyledons or monocotyledons) predominate. The broadleaf trees (especially the dicotyledons) are often referred to as "hardwoods." The FAO/UNEP study makes a separate category for bamboo-dominated forests, but these are included with the broadleaf forests in this report.
- **Conifer forest** is another subset of closed forest. It includes only areas where conifer species (gymnosperms) predominate. These trees are often referred to as "softwoods."
- **Open forest** has trees that cover at least 10 percent of the ground but still allow enough light to reach the forest floor so that a dense, continuous cover of grass can grow. The grass cover increases the likelihood of grazing by livestock and the spread of fires. Open forests generally occur where the climate is relatively dry. The data on open forest areas *do include the land which is forest fallow*. For tropical Africa, data are also available to separate the open forest fallow from the total open forest.
- **Productive forest** is a term used to describe subsets of both closed and open forests. In productive forest, the characteristics of the trees, terrain, and forest regulations potentially allow the production of wood for industrial purposes (e.g., sawlogs, veneerlogs, pulpwood, and industrial poles). The distance to consumption or export centers is not taken into account, so the category includes some forests that are not now economically accessible.
- **Undisturbed forest** is productive forest that has not been logged or cleared in the last 60 to 80 years. The category includes both primary forests and old growth secondary forests. It is not applied to open forests because nearly all open forests have been subject to cutting, burning, and grazing.
- **Logged-over forest** is productive forest area that has been logged or cleared at least once in the last 60 to 80 years but does not fit the criteria for managed forest. This category is not applied to open forests.
- **Managed forest** is productive forest where harvesting regulations are enforced, silvicultural treatments are carried out, and trees are protected from fires and diseases.
- **Unproductive forest for physical reasons** is not suitable for industrial wood production due to rough or inundated terrain or poor growth characteristics of the trees (stunted or crooked).
- **Legally protected forest** is the category for forest where logging is prohibited by law. It includes a variety of parks and protected areas. Illegal logging does occur in some of these areas.
- **Forest fallow** is land that has been cleared for cultivation and subsequently abandoned so that it may again have some woody vegetation. This category also includes patches of land that are being used to grow crops and some patches where forest has not been cleared but are too small to account for separately. The category is not supposed to include land where erosion or leaching have so degraded the site that only shrubs or grasses grow after the land is abandoned. Land in the forest fallow category is excluded from the definition of closed forest but included in the definition of open forest.
- **Plantations** are tree stands that have been established by human activity. The term includes reforestation (reestablishment of a tree cover on deforested or degraded forest lands) and replacement of natural forest by a different tree crop.
- **Industrial plantations** are sites where trees are planted to produce sawlogs, veneer logs, pulpwood, and pitprops. This category excludes plantations that produce fuelwood for industrial use.

- **Social and environmental plantations** are designed for soil and water protection or to produce fuelwood and charcoal, polewood or construction wood for local use, or nonwood products, such as gum arabics. The category excludes plantations for nonwood commodities such as rubber, palm oil, coconuts, cloves, coffee, and cocoa. It also excludes trees planted to shade agricultural crops.
- **Shrubland** has woody vegetation covering at least 10 percent of the ground, but the main woody plants are bushy species with a height at maturity of 0.5 to 7 meters. Shrubland may be the natural vegetation under dry or otherwise stressful conditions, or it may result from severe degradation of open or closed forest land. The data on shrubland areas include some fallow agricultural land.

Figure 12.—Classification of Woody Vegetation

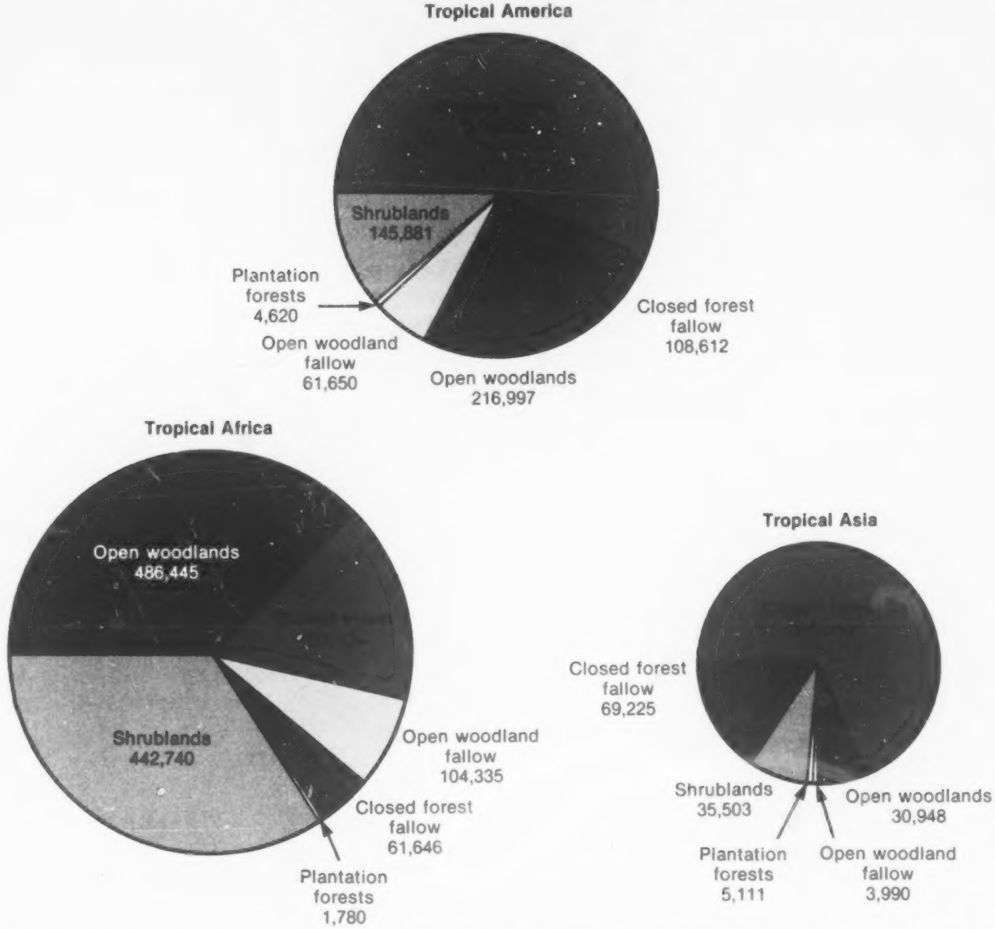

Natural forests
Plantations
Composition/density
Closed forest
Open forest
Alteration by agriculture
Forest
Forest fallow
Forest
Forest fallow
Production capacity (wood for industry)
Productive
Un-productive
Productive
Un-productive
Industrial
Social and environmental
Management status/physical accessibility
Without intensive management
With intensive management
For physical reasons
For legal reasons (parks)
Past logging
Un-disturbed
Logged-over

SOURCE: Adapted from Food and Agriculture Organization/United Nations Environment Programme, *Tropical Forest Resources*, Forestry Paper No. 30 (Rome: FAO, 1982).

by cutting; it is either too steep or too wet for logging or farming. However, this category also includes forest where the trees have no potential for industrial wood production, in some cases due to excessive cutting and consequent resource degradation. Brazil, Indonesia, Peru, Mexico, New Guinea, and Zaire each have at least 20 million ha of forest unproductive for physical reasons. The name of this category is misleading, since much of this forest can be productive for fuelwood and other nonindustrial products and for essential environmental services such as watershed protection.

Finally, about 3 percent of the closed tropical forest has been given **park or other legal protection** status. Again, the percentage of the total hides an unequal distribution. Over half

Figure 13.—Areas of Woody Vegetation[a] in 76 Tropical Nations by Region (thousands of hectares, 1980 estimates)



[a] *Closed forest* has dense canopies and no continuous grass cover. *Open forest* has scattered trees and continuous grass cover. *Forest fallow* is land used or abandoned from agriculture. *Shrubland* has wood vegetation under 7 meters tall.

SOURCE: Adapted from Food and Agriculture Organization/United Nations Environment Programme, *Tropical Forest Resources* Forestry Paper No. 30 (Rome: FAO, 1982).

(55 percent) of the protected forests are located in just four countries—India, Zaire, Indonesia, and Brazil. Despite the legal status of park lands on paper, many of these forests in fact do not receive much protection (3).

Open Forests and Shrublands

Tropical nations contain some 746 million ha of open forest and 624 million ha of shrubland. Whether the natural vegetation of a tropical area is closed forest, open forest, shrubland, grassland, or desert primarily depends on how dry the climate is and on the moisture-holding capacity of the soil. To an increasing extent, however, it also depends on human-caused factors (11).

Generally, closed forests grow where average annual rainfall is above 1,600 millimeters (mm). Open forests are found where rain is from 900 to 1,200 mm. In areas with 1,200 to 1,600 mm of rain, the natural cover may be either open or closed forest, depending on fire history, soil, frequency of drought, and other environmental factors. Shrublands grow where rain is below 900 mm. In transitional areas, fires and livestock grazing can convert closed forest to open forest and open forest to shrubland. Conversely, closed or open forests can be reestablished in some places when fire and other pressures are eliminated (4,11).

Open forest and shrubland areas are unevenly distributed among tropical nations. The data describing these types of forests are much less accurate than for closed forests. This is partly because boundaries between open forest, shrubland, grassland, and fallow agricultural land are difficult to determine. It is also because there has been less interest in measuring or monitoring open forests and shrubland. Table A-3 in appendix A shows estimates for areas of open forest and shrubland in each of the 76 nations. Together, the African nations have most (65 percent) of the tropical open forests, but Brazil again dominates with 157 million ha. Zaire has 71 million ha; Angola has 51 million ha.

Shrublands also are mainly (71 percent) found in Africa. Sudan has 87 million ha of shrubland, and other African nations with large expanses of shrubland include Tanzania, Central African Republic, Zambia, and Ethiopia. In tropical America, Brazil has 61 million ha; Paraguay, Bolivia, and Mexico also have extensive shrublands. Among the tropical Asian nations, Thailand, Kampuchea, Laos, and Indonesia all have substantial shrubland areas.

Since open tropical forests are more easily penetrable than closed forests, nearly all of them have been cut, burned, or grazed by livestock. Hence, no open forests are classified as undisturbed. Two-thirds of tropical America's open forest is classified as productive—having potential to produce wood for industry. In Africa, where these forests are generally drier, only one-third is classified as productive; just over one-fourth is classified productive in tropical Asia.

Although few open forests fit the FAO/UNEP definition for "productive," these woodlands are important for nonindustrial products and services. Much, perhaps most, of the open forest is used for livestock grazing and fuelwood collecting. These forests protect soils and watersheds in the semiarid regions and their wildlife is important as food. Further, many of the trees are legumes capable of converting atmospheric nitrogen to fertilizer, and so they are important for restoring the fertility of abandoned croplands.

Parks and protected areas account for 9 percent of the African tropical nations' open forests. Tropical America has given protected area status to just 1 percent, and tropical Asia has designated 2 percent for protection.

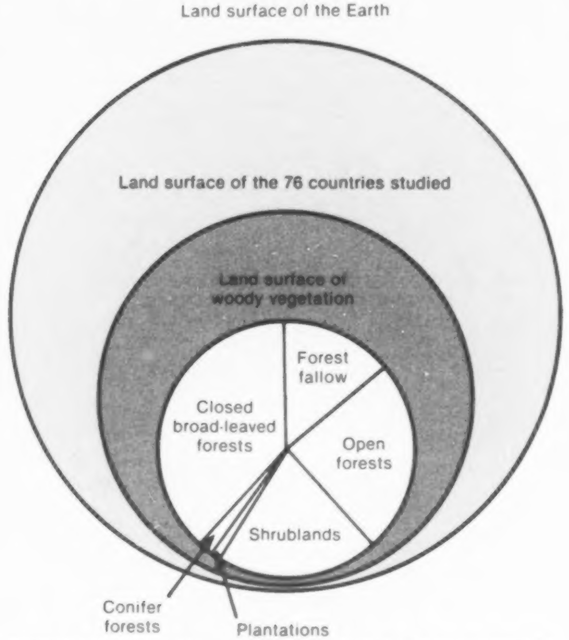
Forest Fallow

The closed tropical forest regions include some 240 million ha of land in forest fallow. Overall about 1 in 6 ha in the closed forests are being used for shifting agriculture. But in many nations, shifting agriculture has claimed a larger part of the closed forest. Sierra Leone has five times as much forest fallow as closed forest. Five other nations in tropical Africa, four in tropical Asia, and four in tropical America have from 50 to 100 percent as much forest fallow as closed forest. Table A-4 in appendix A shows the ratio of forest fallow to forest for each of the 76 nations. It is likely that much of this fallow land will not be returned to forest uses. Under unfavorable site conditions and short fallow periods, much of this land may eventually become unproductive for agriculture as well.

Estimates of forest fallow areas are not accurate. However, shifting agriculture is by no means limited to moist areas. In dry regions, fallow serves to restore moisture as well as organic matter and plant nutrients to the soil. The FAO/UNEP report estimates that about one-fifth of the land reported to be open forest is in fact forest fallow. Livestock graze on both the forest fallow and the open forest that has not yet been used for crops.

Figure 14 shows relative areas of each vegetation type for the 76 nations as a whole.

Figure 14.—Overall Area of Tropical Woody Vegetation


Land surface of the Earth
Land surface of the 76 countries studied
Land surface of woody vegetation
Forest fallow
Closed broad-leaved forests
Open forests
Shrublands
Conifer forests
Plantations

SOURCE: Food and Agriculture Organization/United Nations Environment Programme, *Tropical Forest Resources Assessment Project (GEMS): Tropical Africa, Tropical Asia, Tropical America*, 4 vols. (Rome: FAO, 1981).

FOREST MANAGEMENT

Forest Legislation and Policy

Forest legislation and policy are evolving in tropical countries to reflect a growing awareness of the social and environmental implications of forestry decisions. Many tropical nations substantially revised their forestry laws during the 1960's and 1970's. In many cases, however, the laws look good on paper, but are not well-enforced (7).

Some issues have become more prominent in the last 5 to 10 years. For example, many countries have revised their logging laws and policies to be more restrictive regarding timber allocation from public land, lease terms, concession fees and taxes, annual allowable cut limits, regeneration methods, and export of unprocessed logs.

Other prominent policy issues include accelerating reforestation on degraded lands, protecting watersheds, increasing incentives for industrial plantations and farm forestry, and legislative support for reforesting communal land. Social issues, too, increasingly are being recognized (e.g., the needs of slash-and-burn cultivators and nomadic grazers, domestic fuelwood requirements, and release of forest lands to settled agriculture). Many tropical countries now view conservation as important to economic development and, thus, are more aware of the need to sustain multiple-use of forests, preserve biological diversity, maintain parks and protected areas, and guard against the loss of mangroves.

Some gaps, however, still need to be addressed. There is a need to evaluate tropical forest resource policy, but no organization has such a program. The connection between forests and policies in other sectors such as land tenure and agrarian reform also needs to be assessed.

Forest Ownership

In order to understand the use and loss of forest resources and to devise effective policies for managing forests, it is important to know the legal and de facto ownership of forest lands and trees. The legal status of land may not indicate who has practical control of land use. For example, owners of large properties may appropriate adjoining public lands. Also, slash-and-burn cultivators and other landless poor may occupy communal forests. In fact, tree tenure may differ from land tenure.

The FAO/UNEP report (3) summarizes forest ownership by regions and provides some details at the national level. In tropical America, forest ownerships may be public, private, or communal. Most conifer forests in Brazil and in Central American nations are privately owned. The much larger broadleaved forests are public property, but national laws regarding forest ownership often are contradicted by local practice.

The situation is more complex in tropical Africa where private ownership of forests is rare. Traditional use rights in most forest areas are recognized for hunting, gathering nonwood products, acquisition of fuelwood and construction wood, and shifting cultivation or grazing. People may have exclusive rights over trees that they plant on communal lands. Local community ownership of forest lands in many former British colonies is recognized in national forestry laws. In former French colonies, local rights are not recognized at the national level and all forests are considered state property.

In tropical Asia, 80 to 90 percent of the forest land is state-owned and under the legal control of the forest departments. However, a large part of this land is illegally occupied by forest farmers, both those who practice traditional shifting agriculture and those who try to use the forest land for continuous cropping and grazing. State control over forest lands has been a gradual process, taking place mainly over the past 30 years. The central government in Nepal and some states in India such as West Bengal took control of all forested land from the villages in the 1950's. Papua New Guinea and most of the Pacific Islands are exceptions to this general rule. There, forests are owned by clans and tribes and the government has to negotiate with them for the right to use forest resources.

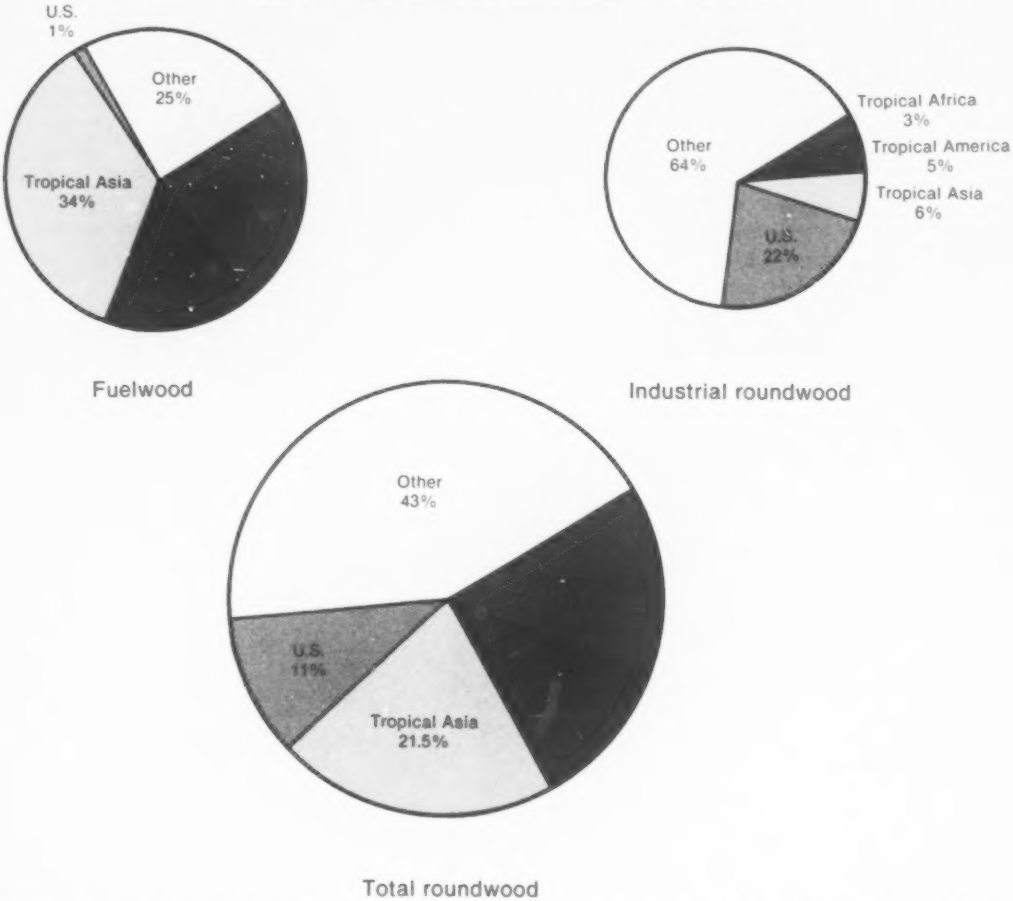
Wood Production

The 76 nations covered by the FAO/UNEP study of tropical forests produce 1.4 billion cubic meters of wood annually (measured as round logs extracted from the forest). As figure 15 indicates, this is about half of all the wood production in the world, and most (86 percent) of it is used for firewood or charcoal. The rest is "industrial wood" used for domestic and export production of sawlogs, veneer logs, lumber, poles, pulpwood, wood panels, and other processed products. Figure 16 indicates changes in wood production for each of the tropical regions over a 12-year period.

The production of industrial wood varies with economic conditions. Generally economic development during the 1970's, resulted in increasing demand for industrial wood in all the tropical regions. Industrial wood production increased most rapidly in tropical Asia and in West Africa with the growth of markets for sawlogs and veneer logs from those regions. More recently, slowing economies have constrained the growth in production. If rapid economic growth resumes, tropical America may experience substantial industrial wood production increases.

Significant investments were made in mills and infrastructure during the 1970's, but these have operated below capacity because of weak markets. In Asia and West Africa, depletion of resources is likely to constrain sawlog and veneer log production, but resurgence of economic growth should create domestic

Figure 15.—Comparative Production of Wood, 1980



Fuelwood

Industrial roundwood

Total roundwood

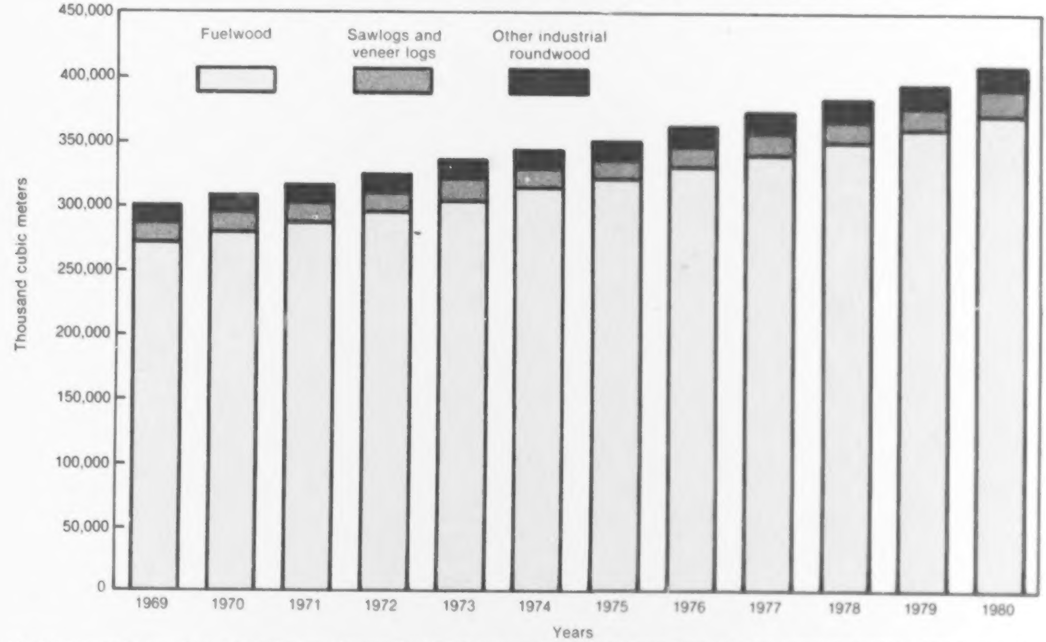
SOURCE: Adapted from Food and Agriculture Organization/United Nations Environment Programme, *Tropical Forest Resources*, Forestry Paper No. 30 (Rome: FAO, 1982)

markets for wood chips to produce pulp and other wood products made from a wider variety of trees.

The increase in total wood production is driven by a steady increase in fuelwood production. However, the data on fuelwood apparently are obtained by multiplying unchanging estimates of per capita consumption by each country's population. Thus, the growth in production is probably not so steady as figure 16 suggests. Nevertheless, fuel is certainly the dominant use for wood in the Tropics and that dominance will become greater where economic growth continues to be slow.

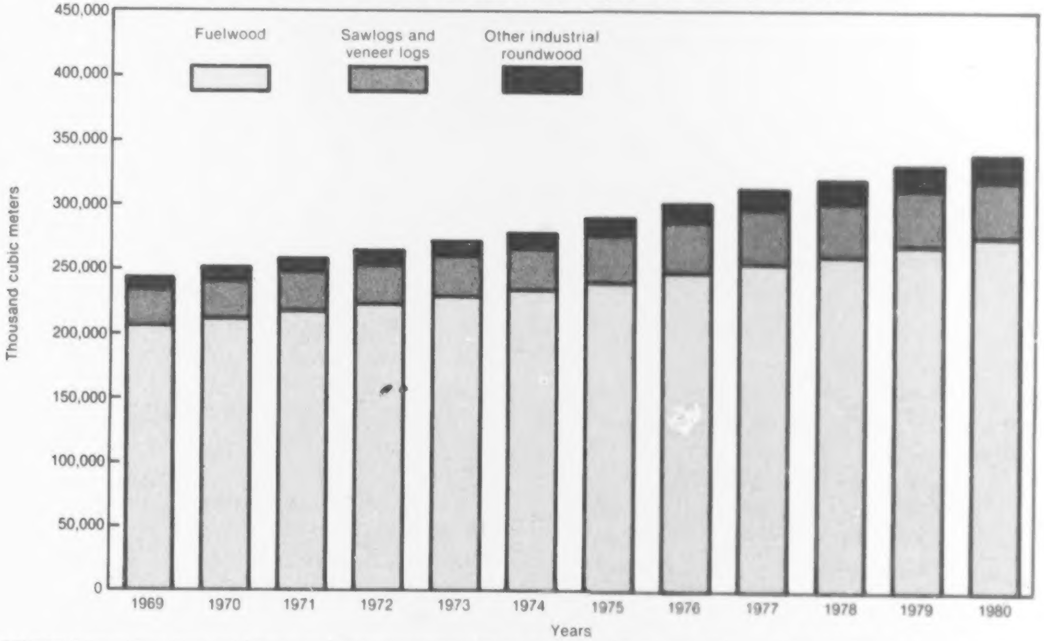
Looking at figure 16, one might expect that tropical forestry efforts would be concentrated mainly on fuelwood production. However, until recently forestry departments in tropical countries, international assistance agencies, and multilateral development banks have concentrated most of their efforts on industrial wood production. Industrial production attracts investment in the forestry sector because it can earn foreign exchange and concession fees, and it can be taxed. Thus, industrial wood

Figure 16A.—Wood Production in Tropical Africa, 1969-80



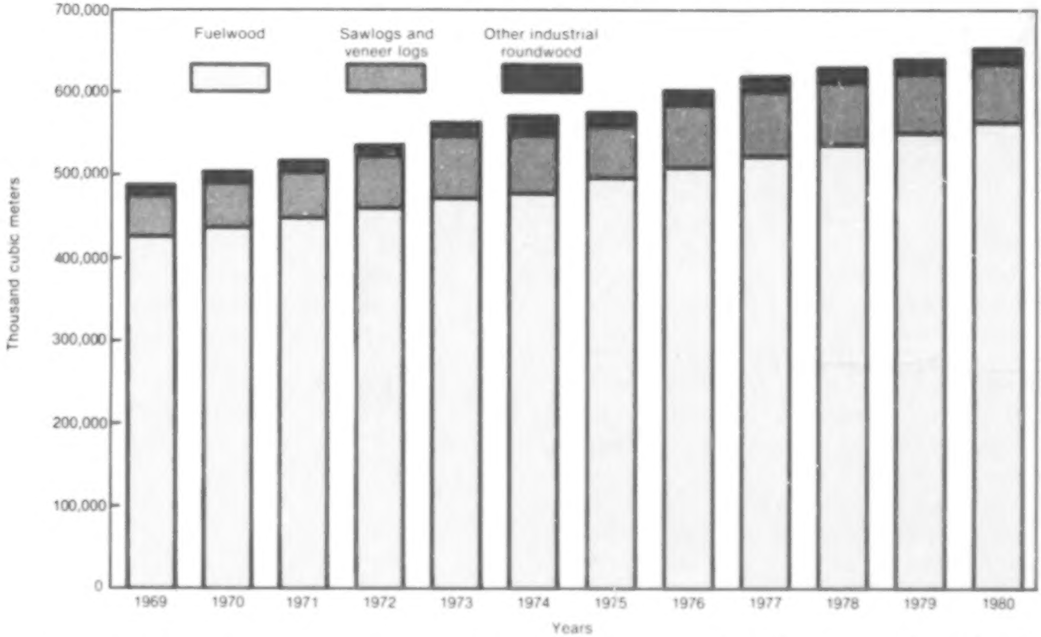
SOURCE: Adapted from Food and Agriculture Organization/United Nations Environment Programme, *Tropical Forest Resources*, Forestry Paper No. 30 (Rome: FAO, 1982)

Figure 16B.—Wood Production in Tropical America, 1969-80



SOURCE: Adapted from Food and Agriculture Organization/United Nations Environment Programme, *Tropical Forest Resources*, Forestry Paper No. 30 (Rome: FAO, 1982)

Figure 16C.—Wood Production in Tropical Asia, 1969-80



SOURCE: Adapted from Food and Agriculture Organization/United Nations Environment Programme, *Tropical Forest Resources* Forestry Paper No. 30 (Rome: FAO, 1982).

production probably will continue to dominate tropical forestry activities.

The problem of ensuring an adequate industrial wood supply for international trade* is more tractable than problems associated with fuelwood supply, impacts of deforestation on soil and water resources, or maintenance of biological diversity. First, nearly 75 percent of the world's industrial wood is now produced in the temperate zone. Second, industrial wood supplies have grown at reasonably stable rates for 30 years (9). And third, a large proportion of the world's future consumption of industrial wood can come from plantations. One recent estimate is that 140 million ha of well-managed plantations could, theoretically, supply all the industrial wood consumed in the world in the year 2000 (8). That would be an area equal to 5 percent of the present forested area in the world.

Much more wood is consumed in tropical countries for fuelwood, however. Serious shortages of fuelwood, lumber, poles, paper, and other forest products within nations are not being met through international trade because of high transportation costs and persistent poverty. Furthermore, conflicts between forest and agricultural land uses are critical in many countries.

Natural Forest Management

Only small areas of tropical forests are under intensive management (3). In tropical America, management is increasing. For example, Mexico is managing watershed forests through controlled logging. Belize, Brazil, Guatemala, and Paraguay are designing management plans for natural resources. Silvicultural trials and research efforts to develop suitable technologies for managing natural forests are under way in Brazil, Costa Rica, French Guyana, Mexico, Peru, and Venezuela.

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*See the OTA assessment *Wood Use: U.S. Competitiveness and Technology*, OTA-ITE-210, August 1983, for an analysis of world markets for industrial woods.

Some African nations, when they were British and Belgian colonies, had developed harvesting regulations and working plans for managing natural forests, but these have been abandoned over the past two decades. Nigeria, Zaire, and Tanzania previously managed large areas of natural forest, but no longer do so. Uganda reports a large managed area, although it is doubtful that the management plans have been implemented. The Congo also is preparing plans that set the allowable cut for natural forests and indicate appropriate silvicultural practices.

The deciduous and conifer forests of South Asia—Burma, Bangladesh, India, and Pakistan—have a long history of intensive forest management. India alone contains 60 percent of all the managed forest in the 76 tropical nations. However, the remaining tropical forests of South Asia and the forests of Southeast Asia are not intensively managed for a number of reasons. Information on forest ecology and dynamics is scarce. Forestry departments lack trained personnel to manage the forests. The emphasis in forestry has been on commercial exploitation so that little attention has been given to silvicultural treatments (3).

Plantations

About 11.5 million ha of tree plantations had been established in the 76 nations by the end of 1980 (table A-5 in app. A). Most (68 percent) of these are in just three countries: Brazil, India, and Indonesia. About 7 million ha are intended to produce sawlogs, veneerlogs, pulpwood, or industrial poles. Only 4.4 million ha have been planted for fuelwood and charcoal, for environmental protection, and for nonwood products such as gum arabic.

The estimated rate of planting in the tropical nations is about 1.1 million ha/yr (4). Current planting is intended mainly (53 percent) for lumber, paper, and industrial poles, but a gradual shift to fast-growing trees to produce fuelwood and charcoal is occurring as a result of changing objectives in tropical forestry.

Forestry plantations are usually monocultures, often of exotic species, planted not where forest cutting is occurring, but rather on land that has been cleared for some time, such as abandoned farmland (5). Most industrial wood plantations in East Africa are softwoods (pines and cypress), while in West Africa hardwoods (principally teak) are planted. In tropical America, pines are usually grown for saw timber, while eucalyptus and *gmelina* are planted for pulpwood. Eucalyptus frequently is grown for pulpwood in India, while teak is grown for timber in India and Indonesia.

Two-thirds of nonindustrial plantations in Africa are for fuelwood; the rest are mainly for gum arabic production or watershed protection. In tropical America, three-quarters of the plantations classified as nonindustrial are eucalyptus trees planted to supply charcoal to the iron and steel industry in the Brazilian State of Minas Gerais. Most of the rest is for production of forest fruit, such as "palmito." Only about 100,000 ha of plantations in tropical America are intended primarily for soil and watershed protection; Mexico has most of these. In Asia, most nonindustrial plantations are intended to produce locally consumed firewood and these are being planted at a rate of about 1 million ha/yr.

The rate of forest plantation establishment is much too low to replace the amount of forest being cleared. In tropical America the ratio of area planted to area deforested annually is about 1 to 10.5; in tropical Africa it is 1 to 29; and in tropical Asia it is 1 to 4.5 (4). Furthermore, most reforestation programs are not carried out where deforestation takes place. In Brazil, for example, plantations are concentrated in the South, whereas forest clearing occurs mainly in the North.

The greatest discrepancy between reforestation rates and the demand for wood and other forest products is in Africa. In Asia, reforestation is closer to deforestation because deforestation rates level off as the remaining forest is left only in inaccessible areas and because severe wood shortages in heavily populated areas are leading to greater planting efforts (4).

DESTRUCTION OF FOREST RESOURCES

Distinguishing between deforestation (also called "clearing" in this report) and degradation of forest resources is important. The FAO/UNEP study estimates deforestation rates for 1976-80 and projects rate estimates for 1981-85. It does not, however, estimate degradation rates. Unlike deforestation, degradation is not easy to identify through time-series Landsat or other remote-sensing analyses.

Deforestation

Each year about 0.5 percent of the remaining closed tropical forests and 0.6 percent of the remaining open tropical forests are converted to nonforest land uses or to wasteland. This is an aggregation of estimated deforestation rates from the 76 countries covered by the FAO/UNEP report. In some countries, the deforestation rate has been estimated by comparing Landsat or other remote-sensing data from two time periods; for some, information on population growth, farming, and animal husbandry practices were considered as well. Table A-6 in appendix A shows estimated areas of closed forest converted to nonforest annually for each of the 76 countries.

Deforestation and Degradation

Much of the confusion over rates of change in forest areas stems from the failure to distinguish between deforestation and degradation. As defined here and in the FAO/UNEP report:

- **Deforestation** is the conversion of forests to land uses that have a tree cover of less than 10 percent. Thus, logged-over areas, including clear-cut areas, are not classified as deforested if the forest is in the process of regenerating.
- **Degradation** of forests refers to biological, physical, and chemical processes that result in loss of the productive potential of natural resources in areas that remain classified as forest. Soil erosion and loss of valuable or potentially valuable genetic types are examples of degradation. In some cases, forests can recover naturally from degradation within a few decades. In other cases recovery may take much longer, if it occurs at all.

The overall tropical deforestation rate is strongly affected by the status of the forests in a few tropical nations that have very large forest areas relative to their population. Thus, the 0.5 and 0.6 percent/yr figures obscure both substantial differences among nations and the overall severity of tropical deforestation. Closed forest area per capita is already less than 0.05 ha in 17 of the 76 nations. Over half the rest have deforestation rates between 1 and 6.5 percent/yr. Table 3 indicates forest areas per capita and deforestation rate estimates for each country.

Table 4 shows the 76 nations divided into nine categories of closed forest area and population size. Several countries, including Gabon, Congo, French Guiana, Surinam, and Guyana, have such large forests and so few people that their deforestation rates are very low. Clearly, closed tropical forests will exist in these nations for many decades, although even a relatively small population can cause resource degradation over large areas. Other nations, such as Liberia and Honduras, have large amounts of forest but also have high deforestation rates. If current rates of deforestation and population growth were to continue, these two nations would, in just 15 years, reduce their forest area per capita to half what it is. In some nations, deforestation can be expected to slow as the forests are reduced to inaccessible areas that are unattractive to farmers. However, experience in nations such as Haiti, El Salvador, Jamaica, Costa Rica, Nepal, Sri Lanka, Angola, and Ghana indicate that deforestation can continue rapidly even when only limited forests remain.

In tropical Africa, deforestation rates are highest in the West African nations. Nigeria and Ivory Coast together incur almost half (45 percent) of the continent's total annual deforestation of closed forests. About 4 percent of the closed forests of the West African nations

Table 3.—Estimates of Per Capita Closed Forest Areas and Deforestation Rates in Tropical Africa, America, and Asia

Country	Closed forest area (1,000 ha)	Closed forest area (ha) per capita	Percent deforested per year[a]
Tropical Africa:			
Ivory Coast	4,458	0.5	6.5
Nigeria	5,950	0.7	5.0
Rwanda	120	[b]	2.7
Burundi	26	[b]	2.7
Benin	47	[b]	2.6
Guinea-Bissau	660	0.8	2.6
Liberia	2,000	1.0	2.3
Guinea	2,050	0.4	1.8
Kenya	1,105	0.1	1.7
Madagascar	10,300	1.1	1.5
Angola	2,900	0.4	1.5
Uganda	765	0.1	1.3
Zambia	3,010	0.5	1.3
Ghana	1,718	0.1	1.3
Mozambique	935	0.1	1.1
Sierra Leone	740	0.2	0.8
Tanzania	1,440	0.1	0.7
Togo	304	0.1	0.7
Sudan	650	[b]	0.6
Chad	500	0.1	0.4
Cameroon	17,920	2.0	0.4
Ethiopia	4,350	0.1	0.2
Somalia	1,540	0.3	0.2
Equatorial Guinea	1,295	4.3	0.2
Zaire	105,750	3.4	0.2
Central African Republic	3,590	1.4	0.1
Gabon	20,500	29.3	0.1
Congo	21,340	12.6	0.1
Zimbabwe	200	[b]	[c]
Namibia	[c]	[b]	[c]
Botswana	[c]	[b]	[c]
Mali	[c]	[b]	[c]
Upper Volta	[c]	[b]	[c]
Niger	[c]	[b]	[c]
Senegal	220	[b]	[c]
Malawi	186	[b]	[c]
Gambia	65	0.1	[c]
Totals	216,634	0.6	0.61
Tropical America:			
Paraguay	4,070	1.2	4.7
Costa Rica	1,638	0.7	4.0
Haiti	48	[b]	3.8
El Salvador	141	[b]	3.2
Jamaica	67	[b]	3.0
Nicaragua	4,496	1.6	2.7
Ecuador	14,250	1.6	2.4
Honduras	3,797	0.9	2.4
Guatemala	4,442	0.6	2.0
Colombia	46,400	1.7	1.8
Mexico	46,250	0.6	1.3
Panama	4,165	2.0	0.9
Belize	1,354	5.0	0.7
Dominican Republic	629	0.1	0.6
Trinidad and Tobago	208	0.2	0.4
Peru	69,680	3.6	0.4
Brazil	357,480	2.7	0.4
Venezuela	31,870	1.8	0.4
Bolivia	44,010	7.5	0.2
Cuba	1,455	0.1	0.1
French Guiana	8,900	129.1	[c]
Surinam	14,830	37.1	[c]
Guyana	18,475	23.1	[c]
Totals	678,655	2.1	0.6
Tropical Asia:			
Nepal	1,941	0.1	4.3
Sri Lanka	1,659	0.1	3.5
Thailand	9,235	0.2	2.7
Brunei	323	1.2	1.5
Malaysia	20,995	1.4	1.2
Laos	8,410	2.3	1.2
Philippines	9,510	0.2	1.0
Bangladesh	927	[b]	0.9
Viet Nam	8,770	0.2	0.7
Indonesia	113,895	0.7	0.5
Pakistan	2,185	[b]	0.3
Burma	31,941	0.8	0.3
Kampuchea	7,548	1.3	0.3
India	51,841	0.1	0.3
Bhutan	2,100	1.5	0.1
Papua New Guinea	34,230	11.0	0.1
Totals	305,510	0.2	0.6

[a] From 1981-85.

[b] Less than 0.05 forest hectares per capita.

[c] No data; in most cases this is where the areas are very small.

SOURCES: Population Reference Bureau, *1983 World Population Data Sheet*, Washington, D.C.; Food and Agriculture Organization/United Nations Environment Programme, *Tropical Forest Resources Assessment Project (GEMS): Tropical Africa, Tropical Asia, Tropical America*, 4 vols. (Rome: FAO, 1981).

are deforested each year. Other African regions with high deforestation rates include East Africa, where 1.4 percent of the closed forest capable of producing industrial wood is cleared each year, and the nations of Burundi and Rwanda, where the rate is 2.7 percent/yr. Large areas of closed forest in Zaire and Cameroon are cleared—262,000 ha/yr together—but like Brazil these countries are forest-rich so the rates do not seem so alarming as in the other African nations.

Five nations in tropical America (Paraguay, Costa Rica, Haiti, El Salvador, and Jamaica) have deforestation rates of at least 3 percent/yr, while another six (Nicaragua, Ecuador, Honduras, Guatemala, Columbia, and Mexico) convert at least 1 percent/yr of their closed forest to other uses or to unforested wasteland. Although deforestation in Brazil is low when expressed as a percent of the remaining forest (0.4 percent), it affects a large area—about 1.5 million ha/yr. That is one-third of all the closed

Table 4.—Comparison of Tropical Countries' Closed Forest Sizes, Population Sizes, and Deforestation Rates

Region/country	Closed forest size[a]	Population size[b]	Deforestation rate[c]
Tropical Africa:			
Kenya	Small	Large	1.7%
Uganda	Small	Large	1.3
Ghana	Small	Large	1.3
Mozambique	Small	Large	1.1
Tanzania	Small	Large	0.7
Sudan	Small	Large	0.6
Burundi	Small	Medium	2.7
Rwanda	Small	Medium	2.7
Benin	Small	Medium	2.6
Sierra Leone	Small	Medium	0.8
Chad	Small	Medium	0.4
Upper Volta	Small	Medium	d
Zimbabwe	Small	Medium	d
Mali	Small	Medium	d
Niger	Small	Medium	d
Senegal	Small	Medium	d
Malawi	Small	Medium	d
Guinea-Bissau	Small	Small	2.6
Togo	Small	Small	0.7
Equatorial Guinea	Small	Small	0.2
Botswana	Small	Small	d
Gambia	Small	Small	d
Namibia	Small	Small	d
Ivory Coast	Medium	Large	6.5
Nigeria	Medium	Large	5.0
Angola	Medium	Large	1.5
Ethiopia	Medium	Large	0.2
Guinea	Medium	Medium	1.8
Zambia	Medium	Medium	1.3
Somalia	Medium	Medium	0.2
Liberia	Medium	Small	2.3
Central African Republic	Medium	Small	0.1
Madagascar	Large	Large	1.5
Cameroon	Large	Large	0.4
Zaire	Large	Large	0.2
Gabon	Large	Small	0.1
Congo	Large	Small	0.1
Tropical America:			
Cuba	Small	Large	0.1
Haiti	Small	Medium	3.8
El Salvador	Small	Medium	3.2
Dominican Republic	Small	Medium	0.6
Costa Rica	Small	Small	2.0
Jamaica	Small	Small	3.0
Belize	Small	Small	0.7
Trinidad and Tobago	Small	Small	0.4
Guatemala	Medium	Large	2.0
Paraguay	Medium	Medium	4.7
Honduras	Medium	Medium	2.4
Nicaragua	Medium	Small	2.7
Panama	Medium	Small	0.9
Ecuador	Large	Large	2.4
Colombia	Large	Large	1.8
Mexico	Large	Large	1.3
Venezuela	Large	Large	0.4
Peru	Large	Large	0.4
Brazil	Large	Large	0.4
Bolivia	Large	Large	0.2
Surinam	Large	Small	d
Guyana	Large	Small	d
French Guiana	Large	Small	d
Tropical Asia:			
Nepal	Small	Large	4.3
Sri Lanka	Small	Large	3.5
Brunei	Small	Large	1.5
Bangladesh	Small	Large	0.9
Pakistan	Medium	Large	0.3
Bhutan	Medium	Small	0.1
Laos	Large	Medium	1.2
Kampuchea	Large	Medium	0.3
Papua New Guinea	Large	Medium	0.1
Thailand	Large	Large	2.7
Malaysia	Large	Large	1.2
Philippines	Large	Large	1.0
Viet Nam	Large	Large	0.7
Indonesia	Large	Large	0.5
Burma	Large	Large	0.3
India	Large	Large	0.3

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[a] Closed forest size classes for this table are: large—more than 6 million hectares; medium—2 to 6 million hectares; small—less than 2 million hectares.

[b] Population size classes for this table are: large—more than 7.5 million people; medium—3 to 7.5 million people; small—less than 3 million people.

[c] Deforestation rate is the percent of the 1980 closed forest area that is being cleared each year during 1981 to 1985.

[d] Indicates the annual deforestation rate is less than 0.05 percent.

SOURCES: Population Reference Bureau, *1983 World Population Data Sheet*. Food and Agriculture Organization/United Nations Environmental Programme, *Tropical Forests Resources Assessment Project (GEMS): Tropical Asia, Tropical America, Tropical Africa*, 4 vols. (Rome: FAO, 1981).

forest clearing each year in tropical America. Colombia and Mexico together account for another third.

Three-fifths of the closed forest cleared in tropical Asia each year is logged-over productive forest and about one-quarter is previously undisturbed forests. The highest deforestation rate in Asia is 4.3 percent/yr in Nepal, and a significant portion of this cutting occurs in temperate forests on mountain watersheds. In Sri Lanka, deforestation is 3.5 percent/yr, and in Thailand it is 2.7 percent. Brunei, the Philippines, and Bangladesh also have very high deforestation rates.

Rates of deforestation are calculated as the estimated area deforested per year divided by the estimated 1980 forest area. Thus, these rates should not be confused with geometric rates of change, such as population growth rates. Acceleration or deceleration of deforestation rates are influenced not only by population growth but also by many other factors such as rural to urban migration rates, land tenure changes, and especially road-building activities. Much too little is known about how these factors interact to predict how deforestation rates will change over any long period.

The FAO/UNEP study does draw some inferences about changes in the accessibility of the remaining forests. The area of closed tropical forest cleared each year may be decreasing slightly for tropical Africa as a whole during the first half of the 1980's, since during the previous decade the closed forests in heavily populated countries of West Africa generally were reduced to sites that are unattractive to farmers. However, the rate probably is accelerating in some nations. Deforestation in Latin America, on the other hand, probably is increasing because additional forested areas are becoming accessible as new roads and bridges are built. In tropical Asia, deforestation is also thought to be increasing, but the rate probably will level off in the 1990's as the forests are reduced to inaccessible areas or sites where agricultural clearing is not worthwhile.

Based on current and planned rates of tree plantation establishment, the areas reforested in the Tropics as a whole are about one-tenth of the areas deforested.

Deforestation also occurs in open tropical forests. Trees are cut and burned both by traditional shifting agriculturists and by farmers intending to establish permanent croplands. Extracting wood for fuel or industrial use, fires, and excessive grazing all cause deforestation by reducing tree cover to less than 10 percent. The open forest area data are poor, however, and the estimates of deforestation rates are even less precise. Deforestation in the dry open forests is typically a gradual process and thus is more difficult to see than in moist areas where the tree canopies are more dense. Further, the open forest lands are often under the jurisdiction of agencies that consider grazing to be the main use of this land. Thus, the land is likely to be classified by its herbaceous cover rather than its tree cover.

The FAO/UNEP study dces not list country-specific deforestation rates for open forests, but it does provide overall estimates of open forest clearing for tropical Africa, America, and Asia. These are shown in table 5. As a rough indicator of the pressure on open forest resources, table A-7 in appendix A indicates open forest area per capita for each of the 76 nations.

Resource Degradation

Resource degradation, the long-term loss of productive potential, is much more difficult to measure than deforestation. Reduction of soil quality and loss of superior genetic types of trees have been documented for specific forest locations (6). But so little is known about the ecology of the tropical forests or the economic potential of the many tropical forest species that degradation can be a highly subjective term. Forest resource degradation is undoubtedly occurring (3,6) and, especially in the drier open forests where recovery is slower, it may be a more important change than deforestation (12).

Table 5.—Annual Deforestation, 1981-85

	Closed forests						Open forests		Total open and closed forests		Area reforested annually
	Undisturbed		Productive, logged		Unproductive						
	(1,000 ha)	(%)	(1,000 ha)	(%)	(1,000 ha)	(%)	(1,000 ha)	(%)	(1,000 ha)	(%)	(1,000 ha)
Tropical America .	1,299	0.29	1,867	2.78	1,173	0.74	1,272	0.59	5,611	0.63	535
Tropical Africa . . .	226	0.19	1,032	2.31	73	0.14	2,345	0.98	3,676	0.52	126
Tropical Asia.	395	0.39	1,278	1.28	153	0.15	190	0.61	2,016	0.60	438
Total	1,920	0.28	4,177	1.98	1,399	0.45	3,807	0.52	11,303	0.58	1,099

SOURCE: Calculated from: Food and Agriculture Organization/United Nations Environment Programme, *Tropical Forest Resources*, Forestry Paper No. 30 (Rome: FAO, 1982).

Forest resource degradation has multiple causes. Logging practices can cause degradation by damaging residual trees, damaging soil, or failing to create an environment where natural regeneration of valuable forest species can occur. Forests in tropical America and Africa typically contain a large number of tree species per hectare, but just a few are commercially valuable for timber. Logging in these areas usually means felling and extracting only the best-shaped, large individuals of selected species. Yet, substantial and lasting damage is often done to the residual trees as a result of mechanized logging and skidding operations (10). As much as one-half of the residual stand may be damaged (e.g., broken stems and branches or disturbed roots) and one-third of the logged area may undergo soil damage (2).

Some tropical forests, such as the *Dipterocarp* forests of South and Southeast Asia, have a large number of commercially valuable species per hectare and are clearcut. This can cause soil erosion that reduces the potential for natural regeneration. In tropical moist forests a large proportion of the ecosystem's nutrients are tied up within the biomass of trees rather than the soils (fig. 17). Thus, a large share of the nutrients may be exported from the forest with the logs. Machinery is available to harvest whole trees and to use multiple species to produce pulpwood. Although these technologies are not yet widely used in the Tropics, they could accelerate the loss of soil fertility (2). Furthermore, many tropical tree species seed irregularly or at long intervals (once in 5 to 7 years). If clearcutting is practiced, natural regeneration of these species may not occur. Clearcutting also reduces regeneration of trees, such as Dipterocarps, whose seedlings need to grow in partial shade (1).

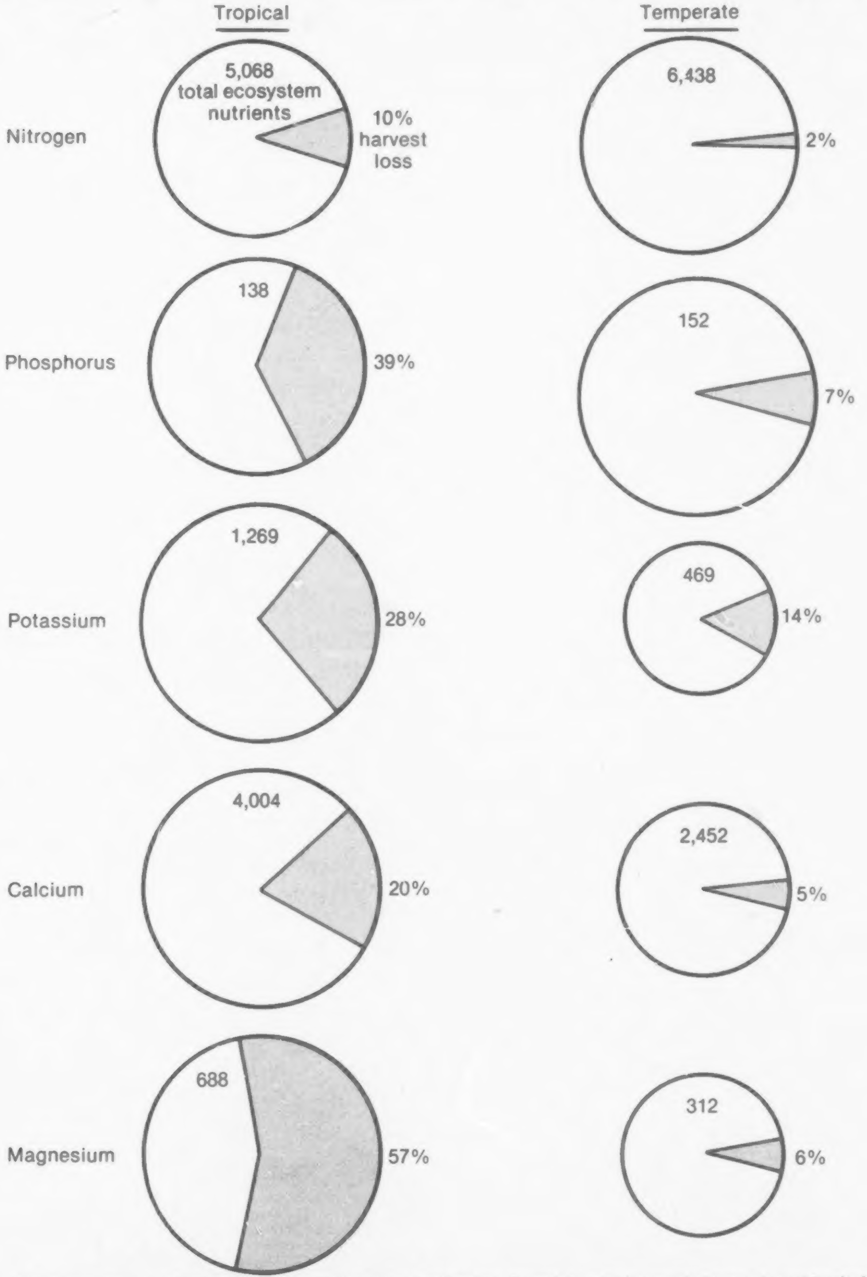
Conifer and mangrove forests in all three tropical regions and certain other forests in tropical America (e.g., "cativo" and "sanjo" forests of Panama and Colombia) also have a low diversity and often are clearcut or cutover so severely that soil conditions are unable to support natural regeneration.

Even where clearcutting is not practiced, logging roads can lead to degradation. For example, in Sabah and the Philippines, approximately 14 percent of forest concession areas are cleared for logging roads (3). Poorly designed or constructed roads cause erosion and water drainage problems and may increase the severity of landslides.

PROJECTION OF CHANGES

The FAO/UNEP study provides some estimates of rates at which forests are being changed from one category to another during the period 1980-85, although quantitative data on natural resource degradation in areas that remain classified as forest are not available. A straight-line projection of the FAO/UNEP estimates, while not a forecast, can provide an understandable way to describe the magnitude of resource changes that may occur. Table 6 shows the projected forest areas for each of the three tropical regions.

Figure 17.—Plant Nutrient Loss Caused by Logging in Tropical v. Temperate Forests



Total ecosystem nutrients (numbers in circle) and the fraction lost through harvest in sample temperate and tropical forests. Values are kilograms per hectare. Shaded area indicates the amount removed when trees are harvested (boles only), assuming that all roots, branches, and leaves remain in the forest.

Temperate data are a mean of four kinds of vegetation from Ovington (1962): *Pinus sylvestris, Pseudotsuga taxifolia, Betula verrucosa*, and *Quercus robur*. Tropical data are a mean of data from Kade, Nigeria and Yangambi, Zaire (summarized in Nye and Greenland,1960) plus Puerto Rico (Odum and Pigeon,1970).

SOURCE: J. Ewel and E. Conde, "Environmental Implications of Any-Species Utilization in Moist Tropics," paper for Conference on Improved Utilization of Tropical Forests, Madison, Wis., 1978, pp. 63-82.

Table 6.—Forest Area Projections (1,000 ha)

	Tropical Africa				Tropical America				Tropical Asia			
Forest Category	1980[a]	1985[a]	2000[b]	Change over 20 years (%)	1980[a]	1985[a]	2000[b]	Change over 20 years (%)	1980[a]	1985[a]	2000[b]	Change over 20 years (%)
Closed forests:												
Undisturbed, productive	118,450	114,134	101,186	−15	454,507	438,119	388,995	−14	101,352	89,087	52,292	−48
Logged, productive	42,848	40,911	35,100	−18	66,622	67,281	69,258	+4	59,847	60,424	62,155	+4
Managed, productive	1,735	1,689	1,551	−11	522	522	522	0	39,790	40,032	40,758	+2
Fallow in closed forests	61,646	66,705	81,882	+33	108,612	116,303	139,376	+28	69,225	73,729	87,241	+26
Physically unproductive or parks and protected areas	53,601	53,236	52,141	−3	157,004	151,140	133,548	−15	104,521	106,836	113,781	+9
Open forests:												
Productive	169,218	159,555	130,566	−23	142,887	136,787	118,487	−17	8,530	8,075	6,710	−21
Unproductive	317,227	315,167	308,987	−3	74,110	73,850	73,070	−1	22,418	21,923	20,438	−9
Fallow in open forests	104,335	111,520	133,075	+28	61,650	62,950	66,850	+8	3,990	4,100	4,430	+11

[a] SOURCE: Food and Agriculture Organization/United Nations Environment Programme, *Tropical Forest Resources*, Forestry Paper No. 30 (Rome: FAO, 1982).
[b] Extrapolated from current rates of change, excludes plantations.

This 20-year projection suggests that at current rates of logging and deforestation in tropical Africa, the area of undisturbed forest would decline 15 percent by the year 2000. Some of this is because timber harvest will convert undisturbed forest to logged forest. The logged forest category also includes secondary forest on land that is recovering from use for shifting agriculture. However, in spite of these additions, the logged forest area is decreasing because this category incurs most of the deforestation for agriculture. Since the land does not sustain continuous cropping, the forest fallow area is expected to increase over the 20-year period by one-third. Changes in the open forests of Africa would be even greater. The open forest fallow is already larger than the fallow area in Africa's closed tropical forests. It would increase by another 28 million ha as productive open forest is degraded to the unproductive category and both are cleared for shifting agriculture.

The projection shows a 14-percent reduction in the area of productive undisturbed forest in tropical America. It also shows a 4 percent increase in the area of logged forest, which suggests that logging of undisturbed forest outpaces clearing of logged forest only slightly. Meanwhile, the forest fallow area in tropical America would increase by only about half as many hectares as are lost from the forest categories, implying that large areas are being converted to nonforest uses other than shifting agriculture. The main reason for converting forest land in tropical America in recent years has been to make cattle pasture, although this use generally is not sustainable in moist forest areas. The area of closed forest that is unproductive for physical or legal reasons is also declining significantly, suggesting that this land is not so inaccessible as its definition implies.

The change rates for tropical America's open forests imply degradation of forest from the productive category, simultaneous clearing of the unproductive forest, and a net increase in open forest fallow that can account for only a fraction of the reduction in the forest categories. Again, this means a net conversion of open forest into cropland, grazing land, and degraded land where forests do not regenerate naturally, and it means a substantial decline in the quality of the remaining open forest.

Tropical Asia shows the highest reduction (21 percent) in undisturbed productive forest, although such forest has already been reduced to an area much smaller than in tropical Africa and America. The logged-over area is increasing slightly, probably because forestry departments in several Asian nations have some control over the spontaneous clearing for cropland that follows logging operations. The area of forests unproductive for physical or legal reasons is increasing in tropical Asia, though whether this is a result of more parks being established or of severe degradation of the logged-over forests is not clear. Open forests in tropical Asia are not so extensive as in the other regions, but the pattern of degradation and deforestation is similar.

Reviewing the FAO/UNEP study's findings on deforestation and resource degradation, Westoby (12) declares that the situation is most alarming in the drier areas, where the data are least precise:

> Among the one and a half thousand million or so hectares of open forest and shrub land, there is an infinite gradation of forest and shrub, ranging from less dry and reasonably wooded forests at one end to extremely arid shrub formations at the other, with the borderline between what can still be regarded as forest and what is irretrievably lost, vague, difficult to identify from aerial photography or satellite imagery, and by no means easy to be sure about when one is actually there standing in it. What is happening to these forests today, under the impact of a variety of pressures, can best be visualized as a steady pushing along the spectrum, a general downgrading, with the result that very substantial areas every year slide out of sight and can no longer be considered as forest on even the most generous definition. But what should be giving concern is not so much the 4 million or so hectares that are sliding off the visible spectrum as the general degradation which is sapping away at the drier tropical forests through the whole spectrum.

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Causes of Deforestation and Forest Resource Degradation

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Chapter 4

Causes of Deforestation and Forest Resource Degradation

HIGHLIGHTS

- Tropical deforestation and forest resource degradation are caused by subsistence agriculturalists, livestock raisers, firewood collectors, and loggers.
- The agents of tropical forest loss vary in prominence among the three major tropical forest regions (American, Africa, and Asia). Many times, the combination of these activities exacerbates forest resource problems.
- In many tropical areas, political, ecocomic, and social forces lead to overexploitation and underinvestment in management of tropical forest resources.
- Regardless of what activities are responsible for forest removal from tropical lands, the soil plays a large role in determining whether agriculture, new forest growth, or barren wastelands will replace the forest in the long run.

HISTORICAL CONTEXT

Deforestation of tropical lands is not solely a recent phenomenon. In fact, the main loss of forests in some places occurred in the 19th century, when forests were cleared to establish plantations of export crops such as sugar, abaca, coffee, indigo, and tobacco (36).

Sugar plantations swept away the Caribbean forests in turn: first Barbados, then the Leeward Islands, Jamaica, and Haiti. The slave rebellion in Haiti left the country in ruins and made possible the sugar boom in Cuba.

Cuba's story is typical and better documented than that of other parts of the Caribbean (7). Upon reaching the northeast coast of Cuba in 1492, Christopher Columbus was impressed by the island's rich forests. A few years later, priest Fray Bartolome wrote that it was possible to walk from one end of the island to the other without leaving the shade of trees. In 1812, forests still covered 89 percent of Cuba. But thereafter, fields of sugar cane began to replace the forests. Fire and axe were used to clear forests for ranching as well. Forest cover had shrunk to 53 percent by 1900. With the declaration of the Republic in 1902, and the subsequent heavy influx of foreign capital into the Cuban economy, forests continued to shrink. Small farms were swallowed up by large plantations. The farmers were driven to eke out a living in the hills where their struggle for survival, together with the insatiable fuel demands of the sugar mills, took a heavy toll on the upland forests. By 1946, forest cover was down to 11 percent of the land area. The average yearly deforestation had been 1.7 percent of the forest area that existed in 1900.

The history of Brazil, which was the world's largest sugar producer until the middle of the 17th century, illustrates the severe damage that deforestation can inflict. The northeastern region of the country is notorious for its poverty. The densely populated coastal region receives substantial rainfall and when the area was forest-covered, its soils were described as fertile and rich in humus. But the forests were cleared for sugar plantations, which were abandoned as the soils wore out. Now the infertile, eroded soils only support savanna. Rainfall is rapidly shed as runoff so that streams and storages dry up during protracted droughts. As a consequence, the region frequently gives rise to mass emigrations (50).

Similarly, little of South China's tropical forests remain except in the extreme southwest and in the interior of Hainan Island. Fire and cultivation took a heavy toll as these forests came under increased human pressure about 1,000 years ago (45). Fire was used widely to clear forests for grazing lands and croplands. Overgrazing and poor agricultural practices further reduced the likelihood that forests would ever reestablish naturally. Timber was used to build houses, temples, and ships, and wood was cut to supply fuel for cooking and heating. Forests probably were eliminated in part to destroy the habitat of dangerous wild animals or to minimize the hiding places for bandits. Today's partly grass covered, eroded, and depopulated hills and mountains in South China attest to the severity of past land-use practices and the inability of the forest to regenerate naturally (46).

In the African Sahel, resource degradation of dry forests has for centuries been caused by a combination of processes including dry and erratic climate, brush fires, trans-Saharan trade, gum arabic trade, agricultural expansion, and cattle. Herodotus and others, writing around 450 B.C., described an active trans-Saharan trade based on precious stones called "carbuncles," gold dust, and slaves. This trade had great adverse impacts on the land. For instance, large areas were cleared of *Acacia raddiana* to produce charcoal. In the late 18th century, huge caravans of 4,000 camels and 1,000 men would stop at the desert margin and cut wood for charcoal to cook and trade. The charcoal even was used as emergency rations for the camels (34).

The resulting encroachment of the desert margin encouraged a southward shift of drysteppe vegetation. This, in turn, altered eco-

Photo credit: OTA staff

Even in areas with abundant rainfall, deforestation can be permanent. Barren landscapes on islands along the south coast of China were deforested hundreds of years ago logical relationships and amplified the impact of hazards such as drought (27). Even though the human populations in the Sahel had suffered periodic droughts for centuries, far greater harm was caused during the 1970's when drought was coupled with a seriously degraded natural resource base. This is the expected response of a resource system where there is self-perpetuating degradation. The problem increases gradually for a long time, but it is typically a logarithmic progression and can lead to catastrophe (11).

For centuries, tropical deforestation has been associated with poverty (17). People displaced by development processes are often the direct agent of deforestation. While peasant cultivators and herders have done the actual tree cutting and burning, the causes lie in a chain of events that have left these people few options but to destroy the forest or starve.

SOIL: ITS RELATIONSHIP TO DEFORESTATION AND LAND DEGRADATION

Soils, by themselves, are not a direct cause of tropical deforestation. They do, however, set the stage in many tropical regions for the practice of shifting cultivation, which causes deforestation. When it is cleared, forest land commonly loses its fertility, produces declining crop yields, and ultimately is abandoned. If forest soils could sustain agriculture, continual relocation of farm fields would be less likely to occur and fewer forests would be cut down. But few tropical forest soils can sustain productive agriculture over the long term. The presence of large areas of either heavily leached soils of low fertility, thin erosion-prone soils, or dry soils makes the establishment of permanent farming sites extremely difficult. Therefore, regardless of what activities are responsible for cutting tropical forests, the underlying soil materials play a large role in determining whether agriculture, new forest growth, or barren wastelands will be the long-term results.

A simple but useful way of discussing tropical forest soil is to divide the forest lands into three categories:

1. hot, wetlands;
2. arid/semiarid lands; and
3. mountainous lands.

Although the soils on certain deltas, young volcanic materials, and flood plains may be fertile, most soils in **hot, wetlands** have significant fertility problems. These soils are formed by **chemical** weathering of rocks. High temperatures and high rainfall combine to accelerate leaching of nutrients from the rock and soil mineral particles. The residual minerals tend to be composed mostly of aluminum, silicon, iron, oxygen, and water, a chemical composition so restricted that many food or tree crops planted on such soils will have stunted growth or will not survive. In some of the soils, silicon and iron concentrations are so low, and aluminum so high, that the soil may approach or reach the composition of bauxite, an aluminum ore.*

These soils have other problems when fertilized with certain essential plant nutrients. Phosphorus becomes so tightly held by certain clay minerals, aluminum, iron, and manganese oxides that plants cannot extract enough for their own benefit (4,13). In the Amazon Basin, for example, 16 percent of the soils suffer this problem. Overall, 90 percent of the Basin's soils (table 7) have a phosphorus deficiency (37). Some 15 percent of the Amazon Basin soils have a poor ability to hold potassium and other common plant nutrients (low cation exchange capacity). If such nutrients are added to the soil as fertilizer, they can be expected to be leached away rapidly (4,13).

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*See Van Wambeke (47) and Fripiat and Herbillon (12) for more detailed information. These are good references on soils of the hot, wet tropics that not only contain the commonly cited information on agriculture, soil names, etc., but also provide discussions of mineralogical and chemical processes.

In addition, an estimated 2 percent of these soils will harden irreversibly upon drying (47), severely limiting reestablishment of vegetation (21). In some cases, soil hardening is so complete that the hardened material can be crushed and used as gravel for road building (24).

Undisturbed tropical forests have an efficient nutrient recycling system. As long as the forest is undisturbed, the nutrient supply remains stable. Soil shaded by the closed forest canopy is cool enough for the abundant organic material to decay gradually. Thus, the forest soils typically have a substantial humus content and can hold the nutrients released by microorganisms until they are absorbed back into the web of tree roots to be recycled again. Slash-and-burn agriculture takes advantage of the humus and of the rapid release of nutrients that occurs when the vegetation is burned. But as soil temperatures rise, the humus is oxidized rapidly, and as the forest is removed, the organic inputs are reduced. Soil with less humus is less able to hold nutrients, and when rain falls the soil fertility fades. If the land is returned to forest fallow soon enough, a new growth of trees can reestablish the soil's humus, the web of roots, and the recycling system.

In **hot, dry lands physical** breakdown of rocks and soil minerals plays a larger role in soil formation. In this process, the particles become smaller, but the chemical composition remains nearly the same and leaching of soil nutrients is low. Physical disintegration can occur in a number of ways; for instance, day and night temperature variations cause rocks and minerals to expand and contract and, in time, crack. Salts and other substances collect in cracks, expanding when wet and contracting when dry, further breaking the grains (3). Another mechanical way particles become smaller is through impact of other windblown grains. And, of course, the growth of plant roots is a powerful agent in breaking up and holding rock and soil particles.

In arid/semiarid areas, nutrients needed by many plants commonly are in the soil but become available to the plants only if sufficient water is available (6). If most of the water evaporates from the soil surface rather than percolating down into the soil, dissolved solids or salts can accumulate as crusts at or near the land surface in concentrations that few plants can tolerate (16).

Mountainous lands, though generally cooler than the other two categories, exist in both wet and dry climates and, thus, either **chemical** or **physical** processes may dominate. Rather than percolating into the ground to form thick soils through chemical weathering, much of the

Table 7.—The Main Soil Constraints in the Amazon Basin Under Native Vegetation

Soil constraint	Millions of hectares	Percentage of Amazon Basin
Phosphorus deficiency	436	90
Aluminum toxicity	315	73
Low potassium reserves	242	56
Poor drainage and flooding hazard	116	24
High phosphorus fixation	77	16
Low cation exchange capacity	64	15
High erodibility	39	8
No major limitations	32	6
Steep slopes (>30 percent)	30	6
Laterite hazard if subsoil exposed	21	4

SOURCE: P. A. Sanchez, D. E. Bandy, J. H. Villachica, and J. J. Nicholaides, "Amazon Basin Soils: Management for Continuous Crop Production," *Science* 216:821-827, 1982.

rainfall runs off the land surface to streams. The soils that do form are easily eroded. Consequently, soils in mountainous lands, in general, are likely to be rocky and thin, except perhaps on the lower slopes (6). Deforestation in mountainous regions is one of today's most acute and serious ecological problems (10).

The presence of organic matter is an important factor in the soil's productivity because it:

- contributes to the development of soil aggregates, which enhance root development and reduce the energy needed to work the soil;
- increases the air- and water-holding capacity of the soil, which is necessary for plant growth as well as helping to reduce erosion;
- releases essential nutrients as it decays;
- holds nutrients from fertilizer in storage until the plants need them; and
- enhances the abundance and distribution of vital biota (31).

Therefore, deforestation, by reducing organic matter, lowers the potential productivity of tropical lands. Thus, when tropical land is abandoned, natural regeneration of the forest may not occur, and replanting the forest may be difficult.

VISIBLE AGENTS OF FOREST CHANGE

Subsistence

Shifting Cultivators

Shifting cultivation is common in the Tropics. The techniques are basically similar everywhere: farmers fell and burn the woody vegetation; then cultivate the cleared ground for 1, 2, or 3 years; and then abandon the site for a long period to forest or brush cover (forest fallow). There are four reasons for shifting to new fields: decreasing soil fertility, reduced soil moisture, pest outbreaks, or excessive weeds that raise labor requirements. Long fallow periods generally allow the land to recuperate and become productive once more.

Shifting cultivators fall into two broad classes: indigenous groups and recent occupants. Indigenous groups have long experience with the local environment and use farming practices that tend to be resource conserving. These farmers traditionally have practiced shifting cultivation using methods particular to them and woven into their family and tribal customs, and sometimes into their religion. Usually the choice of land to be cleared is based on knowledge of nature and soils. The timing of various agricultural activities is determined by specific indications of nature, such as the blossoming of wild plants, the emergence of particular insects, and so on.

In contrast, recent occupants generally are less knowledgeable about local environments and apply farming systems that are more destructive of resources (23). These people also cut and burn part of the forest. But unlike native populations, they may farm the same plot until the fertility of the soil is exhausted or shorten the fallow period so that the vegetation cannot recover. This type of cultivator is often a "colonist" who comes to the forests for land because ownership there is ill-defined or badly protected.

Generally, the new lands are only marginally productive for agriculture. In addition, recent occupants bring with them dietary preferences and agricultural technologies that are suited to intensive culture of the more fertile lowlands. By applying inappropriate farming systems on fragile soils, they often destroy the land's productivity.

A large part* of the agricultural population of Latin America farms on steep slopes. Population growth often leads to increased clearance of forested watersheds and forces many farmers to migrate down the slopes, clearing

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*In most of the tropical countries of Latin America, over 20 percent of the agricultural population is on steep slopes, including 50 percent in Peru and Colombia, 40 percent in Ecuador, 65 percent in Guatemala and Haiti, and 45 percent in Mexico (33).

Photo credit: H. Bollinger

Forested hillsides such as this one in Guatemala are being cleared for agriculture throughout the Tropics in part because of population increases and inequitable land distribution

the forests as they go, even into the inhospitable humid lowlands of the Amazon Basin. In recent decades, colonization by farmers who practice shifting cultivation has taken place throughout tropical Latin America. Colonization was primarily spontaneous in the 1940's and 1950's, but became more systematically planned by government agencies in the 1960's and 1970's.

Even traditional shifting cultivation practices are breaking down under increasing population pressures. Commercial exploitation and subsequent colonization leave less land for traditional cultivators. With limited land and increasing populations, fallow periods have decreased. These shorter cycles do not allow enough time for forests to restore adequate soil fertility. The result is even more extensive forest clearance and a gradual decline in human living conditions.

It is easy to attribute recent increases in shifting cultivation to population pressure and inadequate land outside the forests. But other important factors are involved as well. In many places, good farmable land is reserved for the privileged and not used intensively to produce needed food crops for domestic consumption. Governments may build highways and promote colonization projects as alternatives to land reform (as has happened in Latin America). Some colonization projects are viewed as an effective way to occupy empty territory. This is especially true near frontiers in Brazil and Mexico (28). Still, indications are that forest clearing by peasant farmers will continue to expand with or without government encouragement and assistance.

Livestock Raisers

Nomadic herders in open forests are analogous to shifting agriculturalists in wetter tropical forests. In arid and semiarid areas, nomadic herding is a major land use (43). At one time, the nomadic way of life probably did not degrade the limited resources of dry regions significantly because there was a long fallow period before an area was reused. It is likely that an ecological balance among man, animals, and the surrounding natural vegetation existed. This has changed, however.

Livestock symbolize wealth and provide barter materials and insurance against future disasters (44). Cattle herds have increased in the Sahel in response to economic conditions. For example, the French-speaking Sahel had a fivefold increase in cattle during the 25 years preceding the 1968 drought (14). Cattle, however, are poorly adapted to Sahelian conditions: their conversion efficiency of plants to animal products is poor; they require substantial quantities of water; and they are highly prone to stress. Further, their feeding habits are incompatible with the Sahelian environ-

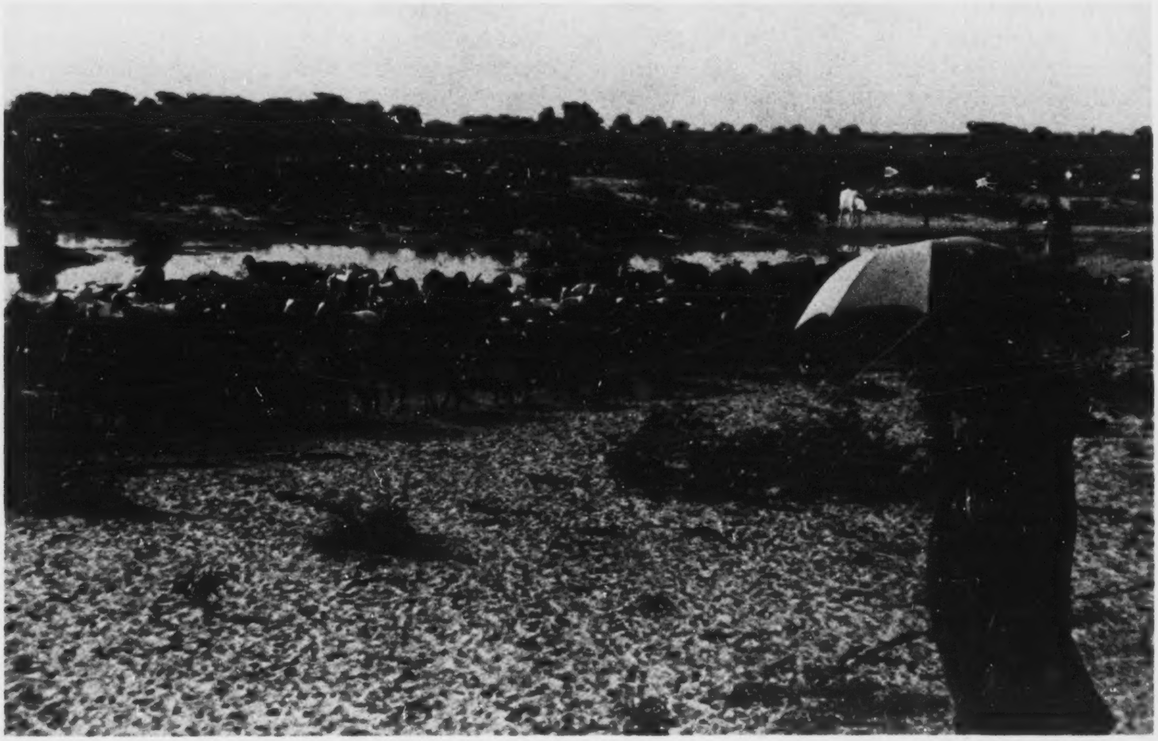

Photo credit: J. Chevalier for FAO

Overgrazing by poorly managed livestock herds is a major cause of deforestation and resource degradation in open forests and shrublands of Mauritania and throughout the semiarid tropics

ment. Since cattle are largely grazers, not browsers, they must be moved very frequently or they may completely eliminate perennial grasses. The reduction of dry-season grasses triggers a number of degradation processes once the seasonal rains begin. Raindrops striking the soil surface raise mud spatters that seal the soil surface to water infiltration. Then overland waterflow erodes the soil.

High-yielding wells have been built during recent droughts to alleviate chronic livestock water shortages. This has led to a rapid increase in the number and size of herds of cattle and small ruminants, which in turn have overgrazed the land in the vicinity of wells. Natural vegetation has disappeared in generally concentric circles around the wells until the grazing resources are so distant from the well that animals nearly starve before they reach forage sites. Meanwhile, parts of the remaining trees in the vicinity of the wells are lopped off for animal feed, and goats overbrowse shrubs.

These effects accelerate desertification, a process that spreads desert-like patches around villages or waterholes as a consequence of continued excessive pressure on the natural environment. Desertification is serious in tropical Africa, Latin America, and Asia.

Fuelwood Gatherers

Cutting trees and woody vegetation to meet the growing demand for fuelwood has accelerated the process of deforestation and now seriously threatens the environmental stability of large areas. Such situations prevail in Africa (especially in the arid and semiarid areas south of the Sahara, in the east and southeast, and in mountainous areas); in Asia (in the Himalayas and the hills of South Asia); and in Latin America (mostly in the Andean Plateau, the arid and semiarid areas of the Pacific coast in South America, and in the Caribbean).

Wood provides two-thirds of all fuel used in Africa, nearly one-third in Asia, and one-fifth in Latin America (2). Among the poor in tropical countries, it is often women and children who collect subsistence firewood. When possible, they avoid felling whole trees. Instead they lop off small branches, twigs, and roots and pick up dead wood from the ground. Men are more likely to collect wood for commercial sale and are more to fell whole trees.

Demand for wood fuels is concentrated in towns, cities, and densely populated farmlands, so the impacts of fuelwood cutting and gathering are greatest around such areas. Eventually, the intense pressures around urban places can lead not only to destruction of the forest but also to complete removal of tree and shrub cover.

It is the commercialization of fuelwood collection that most threatens forests. As towns grow, markets develop for traditionally noncommercial firewood and charcoal. The relatively rich in small towns and fringes of cities, create the demand, while the poor, who are often landless, take advantage of an opportunity to gain income (38). However, if the mar-

Photo credit: OTA staff

Carting firewood for sale in Gujarat, India. Commercialization of fuelwood collection has further exacerbated the fuelwood crisis kets place a price on wood above the price of collecting and transporting it, the trees become valuable. In this case someone is likely to claim ownership and to take over cutting from the landless poor (1).

Fuelwood cutting and gathering often have adverse effects on the land. Maintaining tree and bush cover in arid and semiarid areas is important to prevent desertification. Where fuelwood is available, animal dung and crop residuals are used as fertilizers and compost, but when wood becomes too scarce, these materials are diverted to become fuels. For the very poor, wood scarcity may mean the elimination of cooked food, boiled water, and an essential minimum level of warmth.

Firewood gathering is not the major cause of deforestation in Latin America, but the impacts are great on tropical mountain vegetation. Large circles around mountain settlements have been denuded of woody vegetation. The use of wood and charcoal for industrial fuel is particularly important in Brazil, where it provides 40 percent of the fuel used in the steel industry (42).

Fuelwood gathering has had detrimental effects in Africa and Asia. In the sparsely populated Sahel, areas surrounding population centers are largely deforested. The affected areas continue to grow each year. Until recently, fuelwood was hauled as far as 50 kilometers (km) to large Sahelian towns; now, it is commonly hauled 100 km. Within 40 km of Ouagadougou, the capital of Upper Volta, virtually all trees accessible to roads have been cut to provide fuel for the city's inhabitants. Only a few years ago, fuelwood could be collected in the immediate vicinity of most households; now people must walk half a day to reach it.

Since collection and transport of fuelwood in rural areas is mainly by human and animal labor, its free supply generally is limited to areas within walking distance of the consumer. Rural people will seek fuelwood from more distant locations until travel time becomes too great; then consumption may drop. A survey of India showed that most villages located inside or adjoining the forest meet their total fuel requirements from the forest. At localities within 10 km of the forest boundaries, about 70 percent of the fuelwood used comes from the forest; beyond 10 km, the use of fuelwood from the forests diminishes steadily until at about 15 km it is almost nil (22). However, in nations such as Thailand, with developed road systems and adequate trucks, urban consumers may use fuel or charcoal from much farther away.

Fires

Repeated burning has altered vast areas of tropical forest and woodland. Natural fires are caused by lightning, volcanic activity, spontaneous combustion, or sparks from rockfalls. The majority of manmade fires are set intentionally. Hunters use fire to drive game and to clear bush so that game can be seen more easily. Gatherers use it to encourage the growth of desirable plants and to discourage the growth of others, and to smoke honey bees out of their hives. Farmers use it to clear and fertilize land for planting. Pastoral people use fire to kill insects and snakes and to discourage predators. Other people use fire to ease travel through densely vegetated areas, to make war on neighboring people, or for other reasons. The primary reason, however, is to improve the quality of grasses for grazing.

Repeated fires generally impoverish vegetation and deplete soil through losses of organic matter, reduced nutrient cycling, and reductions in soil microbe populations. Regeneration may be rapid, but plant succession depends on a host of factors including the frequency and intensity of fire. After frequent burnings, fast-growing, light-loving second growth trees and shrubs eventually are replaced by savannas (permanent grass-covered plains). Fires can convert closed forests to savanna and can extend conifer forests at the expense of the broad-leaved forests. Such degradation leads to the establishment of plant communities adapted to physiologically drier conditions.

Seasonally dry forests are being more severely modified than wet forests. Many dry tropical

Photo credit: J. J. Swift for FAO

Park wardens fight a fire in Zakouma National Park, Chad. Uncontrolled fires, often started to achieve short-term gains in forage, destroy long-term productivity over large areas

forests were converted to savannas by human activities long ago. Some savannas are natural grasslands, but these have been expanded beyond their natural boundaries by forest clearing for agriculture and by manmade fires. In many places, it is difficult to determine what savanna is natural and what is derived from human activity, since all savanna vegetation is adapted to frequent fires and appears similar regardless of origin.

Warfare

Warfare has adverse effects on tropical forests. Bombing and shelling of some islands in the Pacific during World War II nearly eliminated the forest cover and the effects remained visible years later (48). Forested areas of Central America, Vietnam, Laos, and Kampuchea more recently have suffered the effects of military conflicts. Dense patterns of bomb and shell craters can eliminate forests or severely damage the trees. In some large areas, forests were removed by plowing and bulldozing to eliminate protective cover for enemy troops. Attempts were made to burn large tracts of dead, defoliated forests, but these largely were unsuccessful (41).

Between 1961 and 1971, about 14 percent of the land surface of Vietnam was repeatedly sprayed with herbicides and defoliants, adversely affecting the forests and mangroves (29). A recent examination of Vietnam's forests some 12 years after the war shows that the long-term effect of spraying on inland forests depended on the dosage (30). An obstacle to reforestation of these damaged lands, which now are covered with coarse grasses, is uncontrolled burning by village farmers even though the land is more suitable for growing trees than farm crops.

The impact of defoliants has been most severe on mangrove forests, as much as 40 percent of which were sprayed. Natural regeneration has brought the regrowth of some minor "weed" species, but commercial species have returned naturally on only about 1 percent of the mangrove area (49). Some replanting has occurred, however, and commercial species have been reestablished in some areas.

Commercial Resource Use

Commercial Agriculturalists and Cattle Ranchers

Few data are available on the amount of deforestation now caused by commercial farming, which usually involves permanent fields with perennial bush and tree crops. This was once a major cause of tropical deforestation, but now it is a less significant cause than shifting cultivation and ranching.

Cattle raising plays a major role in the loss of tropical moist forests in the Brazilian Amazon and in Central America. In contrast, it is not a major factor in moist regions of tropical Asia and Africa, where shifting cultivation and logging are more important.

Photo credit: H. Bollinger

Conversion of moist tropical forest to temporary grazingland in Panama, a common scene throughout Latin America. Most of the beef is exported

Pastures commonly are abandoned after 10 to 15 years of grazing because of declining soil fertility, erosion, soil compaction, invasion of unpalatable weeds, and low productivity. In parts of the Brazilian Amazon, ranches only 5 years old fail because of pasture degradation (19). Pasture instability and degradation result in greater pressure to clear new forests.

The area of pasture in Central America more than doubled between 1950 and 1975, almost entirely at the expense of undisturbed forests. Between 1966 and 1978, 8 million ha of Brazil's Amazon forests were converted into 336 cattle ranches supporting 6 million head of cattle. In addition, some 20,000 other ranches of varying sizes have been established (25).

There are several ways that forests are converted to pasture in Latin America. On large land holdings, forests are often leveled, burned, and seeded with native or introduced grasses. Owners of smaller holdings commonly clear their land by making arrangements with peasant shifting cultivators whereby the peasants clear the land, farm it for 1 or 2 years, and then seed it to pasture and move on (9,32). In southeastern Panama and probably elsewhere, professional deforesters move into national forests, cut the forest, plant grass, and then sell plots as "improved land" (28).

Land consolidation, however, is probably the most common means of converting forest to pasture. Agricultural colonists leave their fields and move elsewhere when yields decline significantly or losses to pests or weeds become too severe. The land is abandoned or sold to more successful neighbors, to a second wave of settlers with more capital, to speculators, or to cattle ranchers. Small plots may then be combined into larger, more efficient units that sometimes are used for tree crops but more commonly for pasture. This process is widespread in tropical Latin America (8).

A number of factors account for the acceleration of cattle ranch development. Cattle ranching, having its roots in Spain and Portugal, always has been a prestigious occupation in Latin America (32). Furthermore, a tradition exists in the Amazon and elsewhere in Latin America that it is the act of deforestation, or other "improvement," which gives one the right of possession of land. The capital costs of ranching are low compared with commercial crop production, and the market for beef is steady or expanding. Government incentives minimize the costs of credit, land, taxes, and production for the conversion of rainforest to pastureland. Finally, strong export markets have encouraged expanded beef production in this region of the world. U.S. companies annually import as much as 330 million lb of Central American beef. That is 25 percent of the region's annual beef production and 90 percent of its beef exports (39), though this imported beef only amounts to about 2 percent of annual U.S. beef consumption.

Several researchers have recommended that the United States ban beef imports from Latin American countries where cattle raising plays a major role in tropical forest destruction (28, 39), or that the United States import no beef from Central America (26). A number of questions would have to be answered before legislation for the first suggestion could be seriously considered. How much time must pass between forest clearing and cattle grazing to avoid the proposed ban? How could it be proven that beef from a particular country is produced primarily at the expense of tropical forests? Who would make the judgment that the beef is produced primarily at the expense of tropical forests? Who would monitor cattle grazing operations day to day in each Latin American country? Such questions need to be examined carefully and answered in detail to deal fairly with other countries. The second suggestion is simpler than the first but the foreign policy implications are equally complex.

A variety of inducements for cattle operations come from international organizations and development agencies. For instance, international agencies and governments provide loans for cattle development, including credit for individual ranchers. Between 1971 and 1977, international and bilateral agencies provided more than $3.5 billion in loans and technical assistance to Latin America to improve livestock production and meat processing (28). In sum, the growth of cattle ranching reflects not only markets but government and international assistance, low cost loans, and other incentives.

Loggers

Commercial logging causes deforestation in moist broadleaved and conifer forests, especially in Asia, West and Central Africa, and parts of Latin America. It is expected that as the Asian wood supply is exhausted, the Latin American share of international trade in tropical wood will increase accordingly, from 16 percent today to about 40 percent by the year 2000 (25). Most tropical American softwoods—and the more valuable hardwoods of tropical Mexico, the Caribbean, and Central America—already are depleted. Most of the remaining timber is in the Amazon, where most of it remains inaccessible and unsuitable for current methods of selective logging.

Logging practices in the tropical forests differ from those in temperate woodlands. Logging companies have markets for only a few tree species, and these are widely scattered in highly diverse tropical forests. For example, in the Ivory Coast only 25 species are regularly cut out of the hundreds available (25). Thus, extensive areas must be worked to get enough logs, and this can be quite destructive. Cutting one tree commonly brings down other trees around it. Additionally, species diversity decreases with repeated selective cutting.

Logging practices frequently influence subsequent natural regeneration and rarely are fol-

Photo credit: H. Bollinger

Lowland tropical forests in Sabah are cleared for plantation crops, but where such projects are poorly managed land can be eroded and ruined before the crops are established lowed by assisted regeneration or intentional reforestation. For timber concessionaires in Asia, tropical silviculture has been a rationalization for cutting economically valuable trees rather than a technique for securing forest regeneration (35). National forestry departments usually exercise only weak control over logging concessionaires.

Even though loggers may gradually degrade forest quality, the relationship between loggers and cultivators exacerbates the rapid depletion of forest resources. These two agents of forest removal reinforce one another. Networks of forest roads designed to transport timber provide entry for farmers. Through a sequence of felling, burning, and cultivation, forest lands are actively degraded to low productivity farms, which in turn may be converted to low-grade grasslands through further burning and grazing. An adequately trained forestry staff rarely is available to police either the logging operations or the movement of cultivators into the concession.

UNDERLYING CAUSES OF FOREST DEGRADATION

In most of the Tropics sustainable forestry and agriculture practices are not being developed and applied. The underlying causes of this failure are institutional more than technical (8,15).

Institutions include national, state, or provincial forestry departments as well as international donor and technical assistance agencies. Institutions also comprise the broad set of rules and arrangements that assign rights to resources, define roles, and govern individual and collective ownerships. Institutions define what individuals can and cannot do, what they can expect others to do or refrain from doing, and what they can expect the government to do on their behalf (15). Institutions set the rules by which policies are applied to produce desired results; policies and actions correspond to the extent that institutions are effective.

Forest degradation represents a case of chronic institutional failure. The two most important factors are:

1. the pattern of property rights and the absence of effective common property institutions for forest-land management, and
2. the ineffectiveness of State and national forestry agencies.

Property Rights and Control of Forest Resources

Forests supply rural people with food, fuelwood, and fodder. A large portion of both moist and dry tropical forests is government owned and people gather freely what they need. Sometimes the government allows such gathering, but more often people take natural forest products whether it is legal or not because the forests are not well policed. Although some forest land is owned by villages or tribes, the individual quest for wood and fodder often overwhelms the collective need to sustain forests. The same principles hold true for other resources. As pressures mount to fulfill human needs, overuse and mismanagement of resources lead to degradation and deforestation.

Growing population is a major force behind this increasing demand, but property rights status (or lack thereof) is an underlying cause of the failure to meet the demand with sustainable production. Use without management is characteristic of natural resource systems that lack clearly defined property rights. When any potentially renewable resource is used in common, no user will delay use or otherwise invest in efforts to sustain the renewability of the resource unless some institution guarantees that he will benefit from the investment. Thus, tropical forests have been degraded because of institutional problems related to control over access to forest land and forest products.

Uncertain institutional arrangements and inadequate administering agencies are at the root of many forest degradation problems. When forests become nationalized, as in parts of Asia, traditional tenure and institutions for common property management of forest lands are abandoned. National governments acquire formal control, replacing local administrations and denying the validity of prior land-use arrangements. The rights of forest occupants to continue using forest land, acquired over generations, have been removed or reinterpreted in the national effort to control people and territory.

Unlike commercial agriculture, which generally takes place on lands where property rights are understood, agreed on, and respected, forestry takes place on lands where complex and often conflicting systems of land tenure apply. This difference creates the acute contrast between investments in technologies to increase agricultural productivity and the lack of such investments in forestry. The lack of clear land tenure will continue to constrain development initiatives in forestry and efforts to reverse forest land degradation. Where communal or national tenure is clear, the lack of capable administration institutions is the major constraint.

The potential for forestry to support national economic development that brings benefits at the village level is great, provided sustainable resource-use systems are applied. But such systems depend on the establishment of institutions to administer forest lands as common property. Developing these institutions will require a better understanding of history, culture, and social organization than is now applied.

To be effective, forest administrations need local support and participation, and this contrasts with how forestry bureaucracies typically work. Unless the institutional component of a forest management technology is understood by villagers to support their goals, that technology will not be used. With respect to villagers in or around public forests, effective common property institutions would clearly define individual and group claims on the benefits that stem from the forest. However, what generally prevails are claims on uses which, in the absence of control over rates of use, drive the resource to depletion (5). Since privatization of forest lands may not be possible in many parts of the Tropics, open access must be controlled through such means as issuing licenses for users, setting quotas, taxing users, or strengthening local social institutions (18).

Transformation of Forestry Administrations

The second part of the issue of institutional change relates to changes in the forestry agencies themselves. Government forestry institutions typically have been designed to protect state or private logging and ranching interests. In many countries, the forest has been a zone of tension between the state and the people. The pattern has been exacerbated by government insecurity with respect to its citizens and borders.

Although agency attitudes and traditions are deepseated, they seem to be changing as government forestry institutions evolve from being custodians of public land to functioning as managers of a development process. For example, in many Asian nations increasing strength is being given to national forestry development corporations charged with managing forests according to sound economic principles. At the village level, small-scale forestry projects for local community development are beginning to be promoted by national agencies. These are intended to create new income for villagers from degraded public forest lands and to reduce pressure on the remaining or regenerating public forest. Some nations have begun to provide forestry extension services for village farmers.

Many Asian nations also have begun to apply policies to encourage investment in wood-processing facilities and to use forest industries within broader strategies of regional development. Few African or tropical American nations have developed such policies, and very few nations in any region have developed feasible long-term plans for forest land allocation.

Even where appropriate policies exist, forest resource development is constrained by poor implementation and reluctance to enforce the policies. The effectiveness of government control over logging concessionaires depends on the degree to which national leaders are committed to maintaining long-term forest productivity. The real value of hardwoods from Asia and West Africa has made it difficult to restrain powerful individuals and firms from enriching themselves by sponsoring illicit cutting, by misrepresenting volume and grade of legally cut logs, or by conferring the rights to exploit the remaining forest to others. Several national governments have banned export of unprocessed logs to encourage forest conservation and local employment. However, data on tropical wood imports by industrialized countries indicate that illicit logging and exporting continue despite the bans (15). The persistence of these problems is due to incentives for rapid economic gains by elite groups and the lack of political commitments to conservation and development of public resources for the benefit of the general public.

Improving forest administration also depends on developing effective participatory approaches to forest management. Through participatory approaches, forestry programs may adapt techniques and institutions to local environments to develop productive and protective forestry systems with an equitable distribution of products. However, substantial obstacles to participatory approaches exist within the implementing agencies and at the local community level. For example, many forestry departments tend to be hierarchical, with highly centralized decisionmaking and little room for delegation. National programs seldom permit field officers to adapt techniques in response to local conditions and provide few incentives for local initiative. Moreover, the current generation of foresters often lacks the necessary skills and resources to provide leadership in this area.

At the community level, common obstacles to participation are the absence of appropriate local organizations and shortage of leadership skills. Typically, even where community development is practiced, inadequate attention is paid to building community problem-solving capacities and to dealing with social diversity in highly stratified village social structures (20). Effective community organization can provide some measure of control over corruption and can restrict the opportunity for individuals in positions of authority to take unfair advantage of their positions at the expense of others (15).

The degradation of forests can in large part be attributed to the failure of state and national forestry agencies to change with changing conditions and to increase the effectiveness of forestry in ways comparable to agriculture. Two especially important tasks are the control of logging concessionaires, which will require political backing from the highest level, and the development of effective participatory approaches to forestry.

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Chapter 5

Organizations Dealing With Tropical Forest Resources

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Chapter 5

Organizations Dealing With Tropical Forest Resources

HIGHLIGHTS

- Many organizations are involved in work to sustain tropical forest resources, but the expertise, knowledge, and funds available are inadequate. This is partly because forestry is a peripheral interest for most of the organizations.
- The limited funds available are not used efficiently because the activities of the many organizations do not complement one another well. There is some prospect that the International Union of Forestry Research Organizations (IUFRO) and the Forestry Department of the Food and Agriculture Organization (FAO) will begin to coordinate the international efforts.
- Coordinating diverse organizations' resource development projects at the national level is the role of the tropical governments. Development assistance agencies have done little to enhance the governments' capabilities for this task, but some promising new programs, such as Cooperation for Development in Africa (CDA), are being developed.
- Because tropical forests are not the central interest of any major U.S. organization, U.S. expertise is widely scattered among many organizations. Cooperative agreements between organizations (e.g., U.S. Agency for International Development/U.S. Forest Service) can bring together this expertise effectively.

THE ROLE OF ORGANIZATIONS

Substantial institutional activity is occurring worldwide that directly or indirectly affects tropical forest resources. The U.S. Agency for International Development (AID), the United Nations agencies, the World Bank, and others have increased their attention to forestry in recent years (16,24). Private corporations and nonprofit organizations also have been involved in the search for solutions to tropical forest problems. And most importantly, the governments of tropical nations have come to recognize that deforestation constrains their economies and their development options. This chapter reviews the types of organizations in the United States and abroad that help sustain tropical forest resources through research, technology development and transfer, institution building, and funding.

U.S. and international organizations play a variety of roles in developing and implementing technologies to sustain tropical forests. The nature of each organization's activities varies with its objectives. Some organizations offer grants or loans, while others carry out research, technology transfer, or education. Some work at the village level, while others are organized for international efforts. Many organizations are mandated to focus on a particular region or a particular issue. Some support the use of existing forests, others concentrate on planting trees for immediate needs, while other organizations conduct the basic or applied research needed to develop sustainable forestry systems for the future. This institutional diversity ensures that there will be no unrealistic search for the "one answer" to tropical forest resource problems.

This diversity of functions and goals, however, can create problems and inefficiencies. Different organizations sometimes work at cross purposes, without knowledge of the other's actions. Similarly, unnecessary duplication of efforts can occur. On occasion, counterproductive competition occurs between organizations or between assistance-giving nations. Often, there simply is a lack of communication between the various groups. Thus, many different groups may carry out many necessary actions, but no one determines whether all the necessary actions are conducted or whether the activities are appropriately timed relative to one another.

Tables 8 through 15 list a selection of important U.S. and international organizations that are involved in tropical forest resource activities. For a more complete discussion of the various institutions listed, see OTA Background Paper #2, *Sustaining Tropical Forest Resources: U.S. and International Institutions.*

It is important not to be misled by the apparently large number of organizations. Even though a great many organizations are involved in tropical forestry work, in few of these are reforestation, forest maintenance, or conservation a high priority. These organizations devote far more staff and funds to other types of development activity than to forestry. In fact, the total amount of funding devoted to forestry remains small relative to the needs. Also, care must be taken to avoid double-accounting, since the forestry funds for some organizations come from the forestry funds of other organizations. Despite the recent expansion of social forestry, international assistance for forestry is still dominated by industrial projects. Analyzing the effects of that dominance, a recent U.S. Forest Service report states:

> Industrial assistance projects cover heavily capitalized pulpmills and sawmill complexes, rather than on-the-ground establishment and management of forest stands. Continuation of this trend would exert greater pressure on existing forest reserves and contribute to the deforestation problem (24).

Table 8.—U.S. Government Organizations

Agency for International Development, Washington, D.C.: International development, institution building with congressional mandate to address forest-related problems in the developing world. AID funding supports other organizations listed in this table

National Science Foundation, Washington, D.C.: Grants for U.S. scientists to do fundamental research in tropical biology

National Academy of Sciences, Washington, D.C.: Funds projects and research on sustaining tropical resources, primarily through Board on Science and Technology for International Development (BOSTID)

Peace Corps, Washington, D.C.: Volunteers for development activities worldwide, including forestry and conservation

Smithsonian Institution, Washington D.C.: Basic research on tropical ecosystems

U.S. Department of Agriculture
- **Office of International Cooperation and Development:** Grants for agricultural research, development assistance, and technical assistance
- **Agricultural Research Service:** Soil and water conservation research; includes Puerto Rico, Virgin Islands
- **Forest Service**
  Pacific Southwest Forest and Range Experiment Station: U.S. tropical forests, Hawaii, U.S. Pacific territories
  Institute of Pacific Islands Forestry: U.S. tropical forests
  Institute of Tropical Forestry (Puerto Rico): Tropical timber management, plantation silviculture
- **Soil Conservation Service:** Soil management support for tropical countries

U.S. Deparment of the Interior:
- **National Park Service (International Park Affairs):** Park planning, management, and conservation training
- **Fish and Wildlife Service:** Assist management and planning for conservation (under the Endangered Species Act, etc.)

U.S. Department of State: Research on tropical ecosystems through MAB (Man and the Biosphere). 1984 funding uncertain

SOURCE: Office of Technology Assessment.

Because the scope of forest problems and opportunities is so extensive and is affected by many interacting economic, social, political, and ecological factors, sustainable development can only be achieved when major changes are instituted by the tropical countries themselves. Actual solutions to the forest resource problems generally will require actions at the village level by local people.

Nevertheless, national and international organizations based outside the Tropics can af-

Table 9.—Nongovernment Organizations Based in the United States

Arnold Arboretum, Cambridge, Mass.: Evolutionary biology

East-West Center, Honolulu, Hawaii: Graduate research, education, and information exchange throughout Asia

International Institute for Environment and Development, Washington, D.C.: Studies sustainable economic and social development, including energy, human settlements, environmental impacts

Missouri Botanical Garden, St. Louis, Mo.: Tropical flora, botany, and research

National Wildlife Federation (International Program), Washington, D.C.: Largest western conservation group: 4.5 million members. International initiative is recent

Natural Resources Defense Council, Washington, D.C.: Legal assistance, monitors natural resource policies and decisions

The Nature Conservancy (International program), Washington, D.C.: Inventory, acquisition, and protection of natural areas

The New York Botanical Garden, The Bronx, N.Y.: Taxonomic research, neotropical plant collection, economic botany

Rare Animal Relief Effort, Washington, D.C.: Environmental education and training in Latin America

Pacific Tropical Botanical Garden, Kauai, Hawaii: Tropical botany

Sierra Club International, Earth Care Center, New York, N.Y.: An information clearinghouse including protection of fragile areas, tropical rain forest mangement and conservation

Volunteers in Technical Assistance, Arlington, Va.: Technical assistance in development-oriented projects

World Resources Institute, Washington, D.C.: Policy studies on natural resources management, particularly in developing countries

World Wildlife Fund-U.S., Washington, D.C.: Funding for conservation of living resources, international wildlife conservation

SOURCE: Office of Technology Assessment.

Table 10.—Consortia

Board for International Food and Agricultural Development: To increase involvement of U.S. agricultural universities in AID

CamCore: Focus on industrial forestry in tropical America

Organization for Tropical Studies: Consortium providing graduate training and university research on tropical biology

South-East Consortium for International Development: Consortium providing development assistance

Universities for International Forestry: Consortium providing experience in forestry and forestry-related problems

SOURCE: Office of Technology Assessment.

Table 11.—Multilateral Development Banks

African Development Bank: Loans total $635 million; U.S. contributes indirectly through Africa Development Fund. Involved in forestry in Ethiopia, Liberia, Ivory Coast

Asian Development Bank: Growing attention to community forestry, including fuelwood and environmental protection

Inter-American Development Bank: Investigating potentials for greater involvement in forestry activities

World Bank: Loans for development. Trend away from monoculture and forest industry toward projects to sustain tropical resources

SOURCE: Office of Technology Assessment.

Table 12.—Major International Nongovernment Organizations

BIOTROP: Information, training, and research institute in tropical forestry and biology

CARE: Renewable resources program promoting conservation of forests and forest dependent resources in the Tropics

Centro Agronomico Tropical de Investigation y Ensenanza (CATIE): Improvement of annual and perennial crop and plant production systems, and animal production on small farms

Permanent Interstate Committee for Drought Control in the Sahel (CILSS): Association of eight Sahelian countries (Cape Verde, Mali, Mauritania, Niger, Senegal, The Gambia, Chad, and Upper Volta) to foster coordination of efforts in the region

Commonwealth Forestry Institute: Associated with Oxford University; reforestation of degraded sites and promoting fast-growing plantations

Consultative Group on Internationl Agricultural Research: Supports and promotes international system of agricultural research centers and programs. Thirteen research centers

Eastern Caribbean Natural Areas Management Program: Research, training, and field projects to strengthen local capacity to manage living natural resources

International Council for Research in Agroforestry: Seven programs: management, information services, training, research/evaluation, technology research, field stations, and special projects

Institute for Terrestrial Ecology: A group of research laboratories in the United Kingdom. Projects on regenerating hardwoods in West Africa and vegetative reproduction of tree species

Intermediate Technology Development Group: Nonprofit organization that offers consultants to developing countries for improving social forestry, household energy, and industrial energy projects

International Development Research Center: Canadian group for development research, including studies of social forestry, agroforestry, and sustainable agriculture. Funded by Canadian bilateral aid

International Society of Tropical Foresters: Information transfer. About 1,000 members

International Union for the Conservation of Nature and Natural Resources: Six commissions: ecology, education, environmental planning, species survival, national parks and protected areas, and environmental policy, law, and administration

International Union of Forest Research Organizations: International cooperation in forestry research through correspondence, seminars. About 10,000 members

Lutheran World Relief: Financial support to other agencies, including Lutheran World Service for tropical forest projects

Lutheran World Service: Community development services, including health care, education, agricultural development. Also reforestation, community forestry

World Wildlife Fund—International: Largest nongovernmental organization for conservation of tropical forests, species, and habitats

SOURCE: Office of Technology Assessment.

fect the willingness and ability of tropical countries to take necessary steps. It is unlikely that bilateral and multilateral aid will fund enough tree planting and conservation to compensate for tropical deforestation and forest degradation. Instead, outside organizations can focus on improving the technical and managerial capabilities of organizations in tropical countries. Following this view, the priority areas for assistance would be forest resource research and technology development, technology transfer, institution building for forest-related education and planning, and measures to increase the productivity and sustainability of agriculture.

Table 13.—United Nations Agencies

Food and Agriculture Organization: Emphasizes agriculture: Has four forestry programs: forest resources and environment, forest industries and trade, forest investments and institutions, and forestry for rural development

United Nations Environment Programme: U.N. coordinating agency for environmental activities

United Nations Educational, Scientific, and Cultural Organization: Tropical forest research, protected natural resources. Includes MAB

United Nations University (Natural Resources Program): International centers for research, post-graduate training, and dissemination of knowledge. Programs in agroforestry, energy

World Food Programme: Supplies food for disaster relief and through Food for Work projects. Some reforestation and woodlot establishment

SOURCE: Office of Technology Assessment.

Table 14.—Private U.S. Foundations Funding Tropical Forestry Research and Projects[a]

1. Ahmanson Foundation
2. Andrew W. Mellon Foundation
3. Atlantic Richfield Foundation
4. Camille and Henry Dreyfus Foundation, Inc.
5. Exxon Education Foundation
6. Ford Foundaton
7. Ford Motor Company Fund
8. Inter-American Foundation
9. John D. and Catherine T. MacArthur Foundation
10. Mobil Foundation
11. Morgan Guaranty Trust Co. of New York
12. Richard King Mellon Foundation
13. Rockefeller Brothers Fund
14. Rockefeller Foundation
15. Shell Companies Foundation
16. Tinker Foundation
17. W. K. Kellogg Foundation
18. Wallace Gerbode Foundation
19. Weyerhaeuser Foundation

[a] In general, few U.S. foundations have substantial international programs. Support for all international and foreign projects amounts to only about 4 percent of the approximately $2.4 billion awarded each year by U.S. private foundations (20). Total U.S. foundation support for tropical forest projects, though difficult to calculate, probably averages between $10 million and $12 million a year.

SOURCE: Office of Technology Assessment.

Table 15.—Major Foreign Bilateral Organizations

Country	Organization	Function
Canada	Canadian International Development Agency (CIDA)	Funds infrastructure for forest industries and conducts inventories and development plans for commercial wood production
France	Centre Technique Forestier Tropicals (CTFT)	Projects include technical assistance, plantation operation, reforestation, and silvicultural research on tropical pines and eucalyptus
Japan	Japanese Overseas Afforestation Association (JOAA)	Tests plantation establishment and maintenance techniques for exotic pulpwood species, mostly in Southeast Asia
Sweden	Swedish International Development Authority (SIDA)	Develops infrastructure for forest industries. Supports community forestry and fuelwood projects, in part through a trust fund for FAO
United Kingdom	Overseas Development Administration (ODA)	Tropical forestry research focuses on silvicultural techniques and genetic improvements of tree species, especially pine
West Germany	Bundesministerium für wirtschaftliche Zusammenarbiet (BMZ)	Funding arm of bilateral assistance
	Gesellschaft für Technische Zusammenarbeit (GTZ)	Implements forestry projects. Priority areas are forest conservation and production, institution-building, and timber technology and processing

SOURCE: Office of Technology Assessment.

TYPES OF ORGANIZATIONS IN TROPICAL COUNTRIES

Research Organizations

Some 40 organizations in tropical countries conduct significant research related to forest resources (23). The majority of these are weak and have been severely constrained by lack of staff and funding. Nevertheless, most of these organizations are carrying out some research to support the recent shift in tropical forestry priorities (e.g., research related to contribution of forestry to rural development, energy production, and conservation and management of tropical forest ecosystems).

Educational Organizations

There are 23 university degree programs in forestry in tropical Africa, 55 in tropical Asia, and 39 in tropical America (15 of these are in Brazil). In addition, tropical Africa has 59 technical schools offering forestry courses, tropical Asia has 118 (49 are in India and 19 in the Philippines), and tropical America has 51 (19 are in Brazil and 14 in Mexico) (7). These numbers may give a misleading impression that there is sufficient capacity in forestry education and training. But most of these schools are new and small, producing few graduates each year.

Some tropical countries, particularly in Southeast Asia, have introduced commendable interdisciplinary resource management programs. A new forestry program in Bihar, India, has a sizable curriculum in related social sciences. Nepal's Tribhuvan University sends all of its graduate students to work in villages for 1 year.

Regulating Agencies

Regulatory agencies with responsibilities related to forests have proliferated in many countries. In addition to forest departments, agencies concerned with planning and finance, agriculture, mines, water resources, energy, parks, wildlife, industrial development, and military matters and internal security have regulations and policies that affect forests in some way. In 1972, only 11 developing countries had environmental ministries or high-level agencies; that number has now reached 102 (9).

In many tropical countries, regulation is hampered by administrative structures, bureaucratic lethargy, low enforcement capability due to remoteness and extensiveness of forest lands, lack of vehicles or fuel, insufficient number or training of staff, and low pay. Where corruption occurs, the policing approach is unable to cope with illegal commercial logging, with excessive hunting and gathering, and with spontaneous agricultural clearing within reserve forests and protected areas.

Project-Implementing Agencies

In most tropical countries, the agencies that are responsible for regulation also implement resource development projects. This can cause some problems in project implementation, especially for social forestry. It is difficult to create a dialog between foresters and local people if the forest department is perceived as a paramilitary organization. Also, paramilitary discipline can discourage innovation within the ranks of the Forest Department, particularly if promotions are based mainly on seniority (21).

One weakness of many project-implementing agencies is that little long-range planning is done. There is a shortage of qualified personnel, good data, and funds for planning (15). In some tropical countries, technical forestry skills are in short supply and many jobs remain unfilled. The foresters often lack the special skills needed for social and environmental forestry (e.g., communications, interpersonal relations management, economics, sociology, and ecology). In many forestry departments, the new types of projects such as fuelwood or social forestry do not have prestige or provide career advancement opportunities. Further, field work is generally left to the most inexperienced staff while the best workers are promoted quickly to central forestry department offices (17).

Nongovernmental Organizations (NGOs)

NGOs concerned with forestry, rural development, and the environment have been established within tropical countries. Examples include the grassroots Chipko or "hug-a-tree" movement in India, Green Indonesia, Earthman Society in the Philippines, Fundacion Natura in Ecuador, Pronatura in Paraguay, Grupo Ecologico Tolima in Colombia, and the Peruvian Association for the Conservation of Nature. The Environment Liaison Centre in Nairobi helps coordinate activities of environmental NGOs, particularly in Africa. NGOs have done important applied research in Kenya and Sri Lanka. In Gujarat, India, NGOs helped spread farm forestry and fuel-efficient woodstoves and crematoria. NGOs in Malaysia, Costa Rica, and Haiti also have implemented projects successfully.

INTERNATIONAL ORGANIZATIONS

Although a great many bilateral and multilateral development assistance agencies and national organizations have programs related to tropical forest resources, the number of international organizations doing significant work on tropical forest resource technologies is much smaller. Five international organizations that have important potential for development and dissemination of technologies that can sustain the forest resources are briefly described here.

Consultative Group on International Agricultural Research (CGIAR)

CGIAR is an association of 13 international or regional research centers concerned with increasing the quantity and quality of food supplies. CGIAR also organizes conferences and training courses and disseminates information. Established in 1971, it has a secretariat based at the World Bank and a technical advisory committee located at FAO. The secretariat coordinates with donors and channels funds to the centers. The total budget for the CGIAR centers exceeded $120 million in 1980.

The CGIAR centers are:

1. International Center for Tropical Agriculture (CIAT), Colombia.
2. International Center for the Potato (CIP), Peru.
3. International Center for the Improvement of Corn and Wheat (CIMMYT), Mexico.
4. International Board for Plant Genetic Resources (IBPGR), Italy.
5. International Center for Agricultural Research in the Dry Areas (ICARDA), Lebanon.
6. International Crops Research Institute for Semi-Arid Tropics (ICRISAT), India.
7. International Food Policy Research Institute (IFPRI), U.S.A.
8. International Institute of Tropical Agriculture (IITA), Nigeria.
9. International Laboratory for Research on Animal Diseases (ILRAD), Kenya.
10. International Livestock Centre for Africa (ILCA), Ethiopia.
11. International Rice Research Institute (IRRI), Philippines.
12. International Service for National Agricultural Research (ISNAR), The Netherlands.
13. West Africa Rice Development Association (WARDA), Liberia.

CGIAR centers could expand into forestry research. By increasing the productivity of food crops, CGIAR research has the potential to reduce land conflicts between agriculture and forestry. However, CGIAR's commodities approach and emphasis on input intensive methods might not be relevant to forestry. In addition, CGIAR has not shown much interest in expanding into forestry; it rejected the Council for Research on Agroforestry's (ICRAF) request for associated status in the CGIAR network (4).

Food and Agriculture Organization of the United Nations (FAO)

FAO, headquartered in Rome, has the largest concentration of tropical forestry expertise in the world. It also has a large number of specialists on assignment in tropical countries. It is important to note that the FAO Forestry Department is dwarfed by the size of the FAO Agriculture Department. Forestry receives less than 8 percent of FAO's total funding, and FAO Agriculture Department publications seldom evidence concern for the relationships between agriculture and forestry. Nevertheless, agriculture and forestry are interdependent, so the agriculture activities of FAO are of critical importance to forest resources.

FAO's Forestry Department is divided into four programs. In decreasing order of size, they are: 1) Forestry Investment and Institutions, 2) Forest Industries and Trade, 3) Forest Resources and Environment, and 4) Forestry for Local Community Development. A Forestry Policy and Planning Service sets overall priorities.

FAO's primary mission is technical assistance, not research or implementation of development projects. It compiles an annual yearbook of forest product statistics and, in conjunction with UNEP, has assessed tropical forests resources and deforestation rates (ch. 3). FAO also has a mandate to support a tree seed bank system, but this has not progressed very far. FAO's Investment Centre assists the

World Bank and the regional development banks in appraising projects. Nearly all forestry projects of the United Nations Development Programme are implemented through FAO's field units.

Although FAO responds to country requests, it also sets priorities for assistance. Current priorities of the Forestry Department include creating a world forest resources information system; improving techniques for the establishment and management of plantations; developing upland forests for erosion control and watershed management; promoting wildlife and park policies; monitoring and evaluating social forestry projects; identifying ways to generate more income from processing wood and nonwood forest resources; and facilitating education, training, and institution building in developing countries. FAO has recently decided to revitalize its Committee on Forestry Development in the Tropics and is expected to use more of its resources for tropical forest conservation and development.

International Council for Research in Agroforestry (ICRAF)

ICRAF is a relatively small organization (about 15 professionals) headquartered in Nairobi, Kenya. Its budget is only one-tenth of the budget of individual CGIAR institutes. But it is the only organization with a mandate to work globally to stimulate, initiate, and support research for development of sustainable agroforestry land-use systems. ICRAF's multidisciplinary team of scientists conducts its own research and trains people from a wide variety of disciplines and organizations in the developing world. In addition, it collaborates with other developing nation institutions on research and development projects. Its long-term program involves: 1) developing interdisciplinary capacity and methods to assess constraints in land-use systems and to identify agroforestry solutions, 2) collecting and evaluating existing agroforestry knowledge, and 3) establishing a program for disseminating information about agroforestry.

ICRAF is governed by an international Board of Trustees and is independent of all other supranational bodies. It receives its operational funds from bilateral donor agencies and private foundations. AID and Canada's International Development Research Center are among the main donors to ICRAF. Since ICRAF is considered a forestry organization, it is not a member of CGIAR, whose mandate does not include forestry. However, ICRAF has indicated that it should be considered an organization developing technologies for use on agricultural as well as forest land.

International Union of Forestry Research Organizations (IUFRO)

IUFRO, based in Vienna, is a loosely knit association of some 600 research organizations involving some 10,000 researchers from 89 countries (3). It does not conduct research but helps to disseminate findings. It sponsors the World Forestry Congress every 3 to 5 years, regional workshops, and a quarterly newsletter. Other than these activities, IUFRO's role has been limited because its funding levels are low. IUFRO is a very decentralized organization, mostly dependent on voluntary cooperation (18). IUFRO is concerned with six main areas of research: 1) forest environment and silviculture; 2) forest plants and forest protection; 3) forest operations and techniques; 4) planning, economic growth, and yield; 5) management and policy; and 6) forest products.

In mid-1983, a research coordinator post was established at IUFRO headquarters. In 1984, IUFRO will sponsor four regional planning workshops on forestry research and technology transfer. These include fast-growing tree species in Asia, fuelwood production systems in Africa, and multipurpose tree species for reforestation of degraded lands in Latin America. The total funding for these research coordination efforts is low.

United Nations University (UNU)

The UNU, chartered in 1975 under the joint sponsorship of the U.N. and UNESCO, was created to be an international community of scholars engaged in research, post-graduate training, and dissemination of knowledge. A central program and coordinating unit is based in Tokyo, but UNU activities take place throughout the world. It does not offer degrees. UNU has never received funds from the U.S. Government.

The university has three principal programs: Natural Resources, Human and Social Development, and World Hunger. In each of these areas, the UNU performs five major functions:

1. to identify and define pressing global problems that can be alleviated through research, advanced training, and dissemination of knowledge;
2. to help fill gaps in knowledge and expertise through internationally coordinated research and advanced training;
3. to strengthen research and advanced training resources in developing countries;
4. to make information available to scholars and research results available to decisionmakers in usable form; and
5. to encourage mission-oriented, multidisciplinary research and advanced training.

The UNU functions through networks of existing universities and research institutes around the world and provides participants with access to a variety of courses, instructors, and research facilities. Special emphasis is placed on interdisciplinary research and training and on disseminating information to international organizations, governments, scholars, policymakers, and the public. UNU has supported research relating to agroforestry ($200,000 per year, primarily in cooperation with CATIE), fuelwood consumption and supply, and land use in arid and semiarid regions.

THE ROLE OF THE PRIVATE SECTOR

Historically, the greatest involvement of U.S. interests in tropical forests has been in the private sector. U.S.-based commercial firms have had forestry operations in tropical regions at least since the early 1900's. The value of tropical hardwoods (logs, lumber, plywood, and veneer) imported into the United States totaled $537 million in 1978. U.S. demand for tropical hardwood sawtimber is expected to increase dramatically over the next two decades. Also, because of the longer growing seasons and faster growth rates possible in tropical forests, the U.S. paper industry is expected to begin using wood from the Tropics for its processes as well.

The extent of private sector involvement in the Tropics has varied because each firm has its own perceptions of its needs and of the current and future economic climate. A few U.S. firms specializing in use of primary resources (e.g., timber or minerals) have contributed substantially to developing technologies for the Tropics and have played an important role both by providing capital for development and by transferring technologies.

Of all U.S. organizations, the U.S-based multinational forestry corporations have had the most to offer and the most to gain in ensuring that tropical forest resources are maintained. These companies are a great storehouse of information and experience in managing forests. Much of this experience was acquired in the temperate zone, but technical know-how can be adapted and transferred in such fields as nursery and seed orchard establishment, tree improvement, pest control, fertilization, silviculture programs, harvesting, transportation, and wood product processing.

Although U.S. forestry companies with operations in tropical nations have in the past concentrated on producing sawlogs and veneer logs, some have recently begun applying their expertise to managing the forests within their concessions for production of a wider range of products and sustainable yields. At least 23 U.S.-based forestry firms (table 16) have operations in the Tropics. About half of these have active forest concessions; the others are involved in pulp and paper operations, research, or have simply set up offices to explore the feasibility of establishing operations in the tropical country (1).

The extent of future investments in the Tropics by U.S. firms is uncertain. Opportunities exist for transfer of both technical and business skills. In some ways, tropical areas have a comparative advantage because they have longer growing seasons. But this is countered by higher infrastructure and transportation costs. Although labor costs are lower in the Tropics than in the United States, it can be difficult to find skilled workers for forest industries.

Table 16.—U.S. Forestry Firms Operating in Tropical Countries, 1981

1. Balsa Ecuador
2. Boise Cascade
3. Crown Zellerbach
4. Champion International
5. Container Corp. of America
6. Continental Forest Products
7. Ford International
8. Gould Paper
9. Georgia-Pacific
10. International Paper
11. International Balsa
12. John Miles Co.
13. Kimberly Clark
14. Olinkraft
15. Pascagoula Veneer
16. Robinson Lumber
17. Resources International
18. Scott Paper
19. Sonoco Products
20. St. Regis
21. U.S. Plywood/Champion
22. West Virginia Paper Co.
23. Weyerhaeuser

SOURCE: J. Bethel, et al., *The Role of U.S. Multinational Corporations in Commercial Forestry Operations in the Tropics*, University of Washington, report for the U.S. Department of State, 1982.

The main obstacle to increased U.S. investment, however, is the political and economic situation in tropical countries. Some countries restrict the share of foreign capital in domestic enterprises, have unfavorable tax or monetary policies, have institutionalized corruption, or involve high risks due to potential economic instability.

Other private industries could also make important contributions to maintaining tropical forest resources. The development of unconventional energy sources could affect tropical forests. Biotechnology firms are improving food and tree crops through tissue culture and other propagation techniques. In the past, some pharmaceutical firms conducted systematic studies of exotic flora for compounds of pharmacological interest (11). Such programs added to the knowledge of tropical ecosystems and provided new, useful substances. Now, however, plant screening is seen as less productive than chemical synthesis of new compounds. Today there are no U.S. pharmaceutical manufacturers involved in a research program designed to discover new drugs from higher plants (6) and the major program, begun by the National Cancer Institute in 1956 to screen plants for antitumor activity, was terminated in 1981.

CONSTRAINTS

Lack of Funds

Constraints on tropical forest resources development occur at various levels: within development assistance organizations, within the recipient countries, and within the local recipient communities. A constraint often cited at all levels is lack of funds. More money, it is so often argued, will bring more results. This is heard from the field, from project designers, and from the organizations themselves when soliciting support from their governments or contributors.

Forestry is a relatively cash-starved sector in many countries where forests do not generate large foreign-exchange earnings. The slow growth of forests compared with the production of annual crops or manufactured goods makes forestry investments seem relatively unprofitable. Even in wood-exporting countries, concession fees and excise taxes on commercial products are often so low that the government does not obtain much profit from forest exploitation. Consequently, finance and planning agencies in tropical countries tend to neglect forestry. Even the multilateral development banks provided little financing for efforts to sustain forest resources until just a few years ago.

Moreover, projects often are left unfinished or without proper followup because funding beyond initial budget commitments is inadequate. This deterioration of projects over time occurs because donors fail to recognize the long-term nature of forestry activities (24). Within countries, it is often easier to start a new project than to secure funds to continue one. Thus, it may be appropriate for development assistance agencies to plan fewer projects but to continue support for longer periods (8).

The problem is, of course, that the current economic climate makes it exceedingly difficult to obtain increased or new funds. Many legitimate development issues needing financial support must compete for a limited resource—money. Thus, while continuing to seek additional financial support organizations also need to search for more innovative and effective ways to use the forestry and agroforestry funds they have.

Obstacles to Effectiveness of Organizations Involved in Forestry Activities in Developing Countries

- **Few donors are involved in forest conservation activities, probably because conservation projects often are not profitable.**
- **A number of donor projects are contributing to deforestation or will fail in reducing the problem because inadequate attention is paid to ecological effects. Road building, agriculture, hydroelectric dams, colonization, and industrial forest harvest projects can be causes of deforestation.**
- **Donor agencies operating in the same country tend not to communicate with each other. This leads to duplication of efforts or failure to learn from the mistakes and successes of others.**
- **Forestry projects are often imposed on local residents rather than being based on what the community wants and needs. As a consequence, many donor projects fail because of "lack of cooperation" from local residents.**
- **Donor organizations often exhibit little acceptance or understanding of the value systems, cultures, and traditions of the recipient countries in the design and implementation of forestry projects.**
- **It is possible to create a negative impact by flooding a country with excessive donor activities or funds. Donor organizations may implement oversized projects in countries not yet ready to absorb them into their existing political and economic structure. Often, when project funding has ended, the country is ill-equipped to carry on because of bottlenecks in education, managerial talents, and other factors.**
- **Projects are often started but left unfinished, or not properly followed up, because of inadequate funding beyond initial budget commitments. Also, donors often fail to recognize the long-term nature of forestry activities in their budget allocations.**

SOURCE: J. Zerbe, et al., *Forestry Activities and Deforestation Problems in Developing Countries*, Report to Office of Science and Technology, AID (Washington, D.C.: U.S. Department of Agriculture and the U.S. Forest Service, 1980.

Lack of Knowledge About Resources and Adequate Technologies

Tropical ecosystems are extremely complex. Further, forest resource problems—and their solutions—are commonly site-specific. Although some basic knowledge about the structure and functions of tropical forests has been known for decades, the kinds of information needed to analyze long-term effects of various management schemes are not available. Thus, site-specific research on biotic resources, soils, and hydrology is needed to plan action that can sustain land-use conversions, maintain the resilience of forests, exploit the wide variety of forest products, and reduce or mitigate offsite impacts.

Many experts believe that the major constraints on sustained use of tropical forests are institutional, social, and political, not technical. They argue that adequate techniques to manage natural forests and plantations, reforest degraded lands, and sustain agroforestry already exist. (Some techniques to reforest degraded lands, for example, are reviewed in OTA Background Paper #1, *Sustaining Tropical Forest Resources: Reforestation of Degraded Lands.*)

Why, then, are these techniques not widely in use? One possibility is that although they are technically feasible, they are not economically attractive. Many of the techniques have not been suitably adapted for developing nations. They are often capital intensive, require heavy or specialized machinery, highly skilled labor, or continuous inputs of imported chemicals—any one of which can make a technology inappropriate. Additionally, poorly understood social or cultural factors often impede technology transfer. Thus, many organizations' efforts to develop forest resources fail to spread beyond the bounds of pilot project areas because the knowledge needed to make the technologies more attractive does not exist or has not been communicated to the project implementors.

Political, Cultural, and Institutional Constraints

Many organizations' efforts are constrained by social factors. Political commitment is often lacking within development assistance organizations or within the counterpart tropical government organizations to allocate more staff and funds to:

- conduct the necessary, long-term baseline ecological and social research;
- provide ecologically sound support for local populations during the lag between investments in trees and realization of the benefits;
- provide necessary, continuous evaluation of projects so that they can be improved as needed; and
- work to meet the needs of local populations.

Forestry projects imposed "from the top down" without adequate community participation commonly fail.

How these constraints affect organizations varies depending on the organization and its purposes. The effectiveness of regional and international research organizations can be greatly constrained where local organizations to adapt technologies to local conditions are lacking. In some cases, capable local organizations do exist but are under political constraints that limit their communication with international groups.

National governments' attitudes toward tropical forest resources are often a major constraint on investment to sustain the resource base. Forestry concessions are often viewed just as revenue-raising devices rather than also as forest management tools. Political leaders who may be voted out of office or deposed rapidly often have a short planning horizon, viewing forest land as a commodity rather than a resource. Or some special interest may be able to get sizable short-term profits from destructive use of tropical forest resources. Legislation is needed to promote integration of forestry and land-use planning, but only a gradual education process can assure government backing for such policies.

Lack of Communication

One constraint often emphasized is inadequate communication. Resource development suffers when researchers or field staff do not communicate with each other, when project planners do not communicate with recipients, and when donor agencies do not communicate with other agencies. And prospects for sustained resource development are dim when projects do not complement one another as sequential steps in an overall strategy. But improving communications and coordination is more difficult, and more expensive, than might be expected. Distribution of timely information, especially when the most important audience is in developing countries, can face many obstacles, both logistical (delivering information to appropriate recipients) and human (finding appropriate readers and inducing them to read and use the information).

Encouraging donor agencies to communicate and coordinate with each other should be a less formidable task, but in reality it is not. First, there are a great number of national, international, regional, and local institutions to track. Many agencies simply do not have the capacity to do this. Communicating with other agencies is often seen as an inappropriate infringement on staff time simply because interagency coordination is seldom an explicit objective in agencies' policies. In some cases, donor organizations compete with each other for influence and thus avoid communication. More often, there are simply too many other things for an organization to accomplish with limited staff and funds.

Contradictory Efforts

There is a lack of consensus and unified policy on how to reconcile economic development of tropical forest resources with the need to preserve biological diversity and other nonindustrial forest functions. This sometimes leads to organizations working at cross purposes. At times contradictory efforts are accidental; one donor agency simply may not know what other agencies are doing. Occasionally an organization's own efforts can seem confused—one branch financing a reforestation project while another finances the conversion of undisturbed forest into agricultural land.

Sometimes such apparent conflicts are the inevitable result of different organizations having different goals. For instance, the CGIAR institutions strive to increase and promote agricultural production and expansion. The expansion often occurs at the expense of forests and in conflict with organizations that are working to prohibit agricultural clearing on forest lands that cannot sustain it. In times when development funds seemed more plentiful, coordination of effort may have been less important. But today coordination is essential to assure efficient use of existing funds and staff.

OPPORTUNITIES

The constraints discussed in the previous section are not insurmountable. Some of the leading multilaterals such as World Bank and FAO have begun to shift their forest development priorities from nearly total emphasis on industrial forestry to community forestry, agroforestry, and institution building. While there is criticism that implementation of these new priorities has lagged (24), the shift in policy is an important beginning. Several strategies exist to further improve the capabilities of organizations that develop, transfer, and implement technologies to sustain tropical forest resources.

Greater Cooperation Between U.S. Government Agencies

Because tropical forestry is peripheral to the interests of U.S. organizations, the U.S. expertise on tropical forests is widely scattered (13). No one organization can assemble an adequate team for tropical forest resource development from its own staff. However, cooperation between organizations can be fruitful. Two of the most productive cooperative agreements are the Forestry Support Program and the Forest Resource Management Project.

The Forestry Support Program is a joint effort of AID, Forest Service, and the Office of International Cooperation and Development. It provides forest service personnel to help AID in designing, managing, and troubleshooting field projects in forestry and natural resources. It maintains detailed files on hundreds of U.S. forestry and natural resources experts. It provides general forestry information and facilitates exchanges of technical information among natural resource personnel on AID and Peace Corps projects. Evaluation of the program has indicated that it has substantially enhanced the cost effectiveness of AID's development assistance efforts in forestry (5).

The Forest Resource Management Project, in which the Peace Corps and AID collaborate, has assessed forestry activities for many tropical nations, conducted regional forestry programing workshops for AID, Peace Corps, and ministry staff in several countries, conducted pre-service and in-service technical training programs, and initiated several modest reforestation pilot projects. The Peace Corps efforts have been funded by AID and given technical support from the Forestry Support Program.

Several existing laws can be used by U.S. agencies to transfer staff and resources and increase the coordination and cooperation of U.S. Government agencies in development assistance. The Foreign Assistance Act (22 U.S.C. 2357(a)) provides several mechanisms for interagency cooperation. Temporary duty assignments (TDY) can be arranged for specific tasks up to 6 months. Participating Agency Services Agreements (PASA) are for time-specific, reimbursable exchanges of staff for up to 2 years. Resources Supply Services Agreements (RSSA) allow for other types of reimbursable cooperation. Cooperative agreements allow exchanges of staff and resources between agencies without charge. The Government Employees Training Act (ch. 41, Title 5 U.S.C.) and the Economy Act (31 U.S.C. 686) also provide authority for reimbursable cooperation between Federal agencies. Although AID has some agreements of this sort with other Federal agencies, the full potential of their use in foreign assistance activities has not been realized (22).

Redirecting International Organizations

Multilateral development banks and some U.N. agencies provide capital and technical assistance for forest resource development. But their forestry efforts are small relative to their other rural development programs. Further, the unplanned impacts on forests of other projects may well be greater than the effects of the forestry projects. Some development projects contribute directly to deforestation—for example, large hydroelectric plants, extensive cattle ranches, and resettlement schemes based on unsustainable agriculture (2). Although the multilateral development banks have signed a joint "Declaration of Environmental Policies and Procedures Relating to Economic Development," little has yet been done to include comprehensive environmental assessment in the project planning process (12).

Through existing mechanisms, the United States has considerable influence over activities of multilateral development banks and U.N. agencies. However, the United States has not fully exercised its influence to promote projects that sustain renewable resources and to avoid projects that harm long-term resource productivity. Doing so would have a significant effect on tropical governments. Countries often are able to obtain substantial cofinancing from other sources for activities supported partly by multilateral development bank loans. Thus, governments can be motivated to modify their development policies to harmonize with those of the development banks.

Some actions that U.S. representatives to the multilateral banks and U.N. agenices could promote include:

- instituting environmental impact assessment procedures,

- improving monitoring and evaluation of projects for their environmental impacts,
- increasing environmental staff and budgets,
- reporting environment-related activities annually, and
- removing restrictions on information about projects to allow greater outside scrutiny and accountability (19).

The mechanisms for accomplishing these reforms differ for each multilateral development bank and U.N. agency.

U.S. Representation to the Multilateral Development Banks

The U.S. Treasury Department's Office of Multilateral Development Banks oversees administrative budgets and policy papers for the multilateral development banks. It also evaluates loans on the basis of legislated, political, and economic concerns. The predominant concerns are human rights and the production of citrus, sugar, and palm oil that could affect U.S. producers. Most of the office's work is in reviewing the projected economic returns of loans. Recently, this office sought advice from U.S. embassies on loans in their respective countries.

The United States has representatives on the boards of directors of the multilateral banks. Voting rights are allocated in proportion to each nation's contribution to the bank's budget. The United States has 19 percent of the total voting power on the World Bank's Board, 5 percent at the African Development Fund, 13 percent at the Asian Development Bank, and 35 percent at the InterAmerican Development Bank. However, a formal vote is rarely taken because decisions on projects generally are made by consensus. A country can push to have formal votes recorded. Ordinarily, problem projects are simply blocked from reaching the agenda. In 1982, the U.S. Government opposed 17 projects proposed by the banks. The multilateral development banks can fund only those activities requested by governments; however, the banks can impose conditions on project implementation in loan agreements.

U.S. Representation to U.N. Agencies

The International Development Cooperation Agency (IDCA) establishes the overall budget and policies for U.S. participation in UNDP, FAO, WFP, UNEP, UNESCO, UNICEF, OAS Technical Assistance Funds, U.N. Capital Development Fund, U.N. Educational and Training Program for Southern Africa, and the U.N. Disaster Relief Organization. The State Department's Office of International Organizations and Programs has lead responsibilities relating to several U.N. agencies.

The United States maintains permanent representatives to the U.N. agencies and has special delegations who present U.S. policy positions and vote on specific country programs. Like all other countries, the United States has only one vote on the governing boards of U.N. agencies. However, the United States can exercise considerably more influence due to its budget contribution. Until recently, UNDP's Governing Council voted on particular projects. Now these decisions have been decentralized and the U.S. representatives no longer even receive copies of project documents routinely. The FAO/UNEP Committee on tropical forestry is another vehicle by which the United States can participate in setting the priorities of these two organizations.

One way of increasing the role of U.S. experts is to begin participating in the U.N. Associate Experts Program. Under this program, the U.S. Government would pay the salary costs of sending U.S. technical personnel to developing countries to work on U.N. agency projects.

Increasing Coordination Among the United States, Other Bilateral Donors, and Multilateral Aid Agencies

Coordination among the United States, other bilateral donors, and multilateral aid agencies can be improved. One vehicle for such coordination is the Development Assistance Committee (DAC) of the Organization for Economic

Cooperation and Development (OECD).* DAC undertakes "Annual Aid Reviews" on the volume and terms of assistance. Few agreements have been reached through DAC, and those that have are not binding or are vague (14). Nevertheless, DAC provides a forum for exchanging ideas. It has encouraged some countries to establish new programs and change existing ones.

U.N. agencies seem to be appropriate organizations for international coordination. The U.N. Commission on Trade and Development has made efforts to coordinate but these have led to confrontation rather than constructive problem-solving. The U.S. Department of State believes that FAO is best suited to coordinate the international forestry activities that are not country-specific (8). However, AID does not aggressively seek FAO coordination of its forestry efforts.

Coordination also needs to be improved at the country programing level. Such programing should involve the preparation of multiyear plans by the recipient countries or ad hoc committees of donors so that the various donors can support complementary projects. With such planning the development assistance agencies would not compete for host country experts or other resources. Through DAC, the United States has advocated greater use of country programing since the early 1960's (14), arguing that it would result in more cost-effective development assistance. In the simplest model, each donor would proceed separately after obtaining a coordinating organization's agreement on a project. However, another possibility would be for several donors to combine resources and expertise on joint projects.

Successful coordination requires: 1) active interest and participation of the donors and the recipient countries; 2) good planning capability; and 3) strong leadership (8). In practice, securing cooperation is not easy. Donors are often reluctant to change plans to conform to those of a coordinating organization. If a foreign or multilateral organization attempts the coordination role, recipient countries may feel that their sovereignty in negotiating with the donors is being compromised.

Some attempts have been made to coordinate country programing for forest resource development. Nepal has tried to designate a lead donor for particular types of projects in certain regions of the country, but this has not been accomplished. Honduras has a Governmental Department of International Coordination, but this has done little to improve coordination because the Department only reviews projects after they have been approved by the various implementing agencies (8).

In response to pressing problems in one region of Africa, the Club du Sahel was established in 1976 by donors in Paris. The United States provides some participants to this group. An African group, the Interstate Committee for Drought Control in the Sahel (CILSS) also works in this area. Enlisting the cooperation of donors and recipient countries was made easier by the crisis situation in the Sahel.

Cooperation for Development in Africa (CDA) is an informal group of bilateral donors established in 1982 at the initiative of France. The participants include the United States, Belgium, Canada, France, Germany, Italy, the United Kingdom, and numerous African nations. The multilateral development banks do not participate officially but may send observers to CDA meetings. CDA consists of ad hoc committees of representatives organized to address particular development topics. The United States is the lead donor nation for the committee on forestry and fuelwood. The committees discuss the types, location, and timing of projects. They do not undertake directly to exchange information on technologies or evaluate lessons learned during projects. CDA also is making an effort to find activities that are too large for a single donor to take on but are appropriate as joint development assistance ventures.

The CDA Forestry and Fuelwood Technical Committee takes a national focus, not a regional one. It initially operates in only five countries—Burundi, Malawi, Senegal, Somalia, and Upper Volta—in order to demonstrate the workability of the process (10). Criteria for selecting countries include: 1) commitment of the country to coordination of assistance, 2) potential for success, 3) need, and 4) existing multiple CDA-donor programs. The committee plans to add Mali and the Sudan and to consider inclusion of Cameroon and Kenya (4). More African countries are involved in other CDA technical committees.

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*OECD member countries are Australia, Austria, Belgium, Canada, Denmark, Greece, Iceland, Ireland, Japan, Luxembourg, the Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom, and the United States. Yugoslavia has special status.

The CDA process is well under way in Senegal and Somalia, where it has been successful because of government commitment. The process does take staff and resources from both donor and recipient country agencies. It has not been so successful in Upper Volta, which is so flooded with development projects that it is unable to implement them well. Upper Volta also lacks a national forestry plan. In Burundi and Malawi, the process is barely under way, but appears to be working. There have been no major problems in CDA donor competition (4).

Greater Reliance on NGOs and Universities

In the past few years, U.S. AID has channeled an increasing amount of money through nongovernmental organizations (NGOs) in tropical countries, especially through private voluntary organizations. This appears to be an effective way to promote technology transfer. NGOs offer particular advantages for small-scale and innovative projects, since in some cases they can act with greater speed, more midproject flexibility, or more public confidence than government agencies. Grass roots environmental movements within tropical countries also may deserve increased international support. Some development assistance programs explicitly exclude NGOs while others do not exclude but still underuse them.

U.S. NGOs could be made more effective by using the Intergovernmental Personnel Act (IPA) of 1970 (ch. 33, Title 5 U.S.C., subch. 6) to arrange exchanges of personnel for up to 2 years between Federal agencies and universities or nonprofit research organizations. Some U.S.-based NGOs are eligible for IPA exchanges, but transfers of U.S. Government personnel to NGOs are uncommon. The Office of Management and Budget (OMB) has recommended that IPA arrangements with universities be limited to tenured faculty, but this seems likely to have detrimental effects on the availability and development of U.S. expertise to solve forest resource problems.

The Foreign Assistance Act (22 U.S.C. 2357(a)) allows Federal agencies to provide training to: 1) personnel or sponsored fellows of international organizations in which the U.S. participates, 2) certain quasi-public organizations such as the Red Cross, 3) voluntary nonprofit relief organizations approved by the Advisory Committee on Voluntary Foreign Aid, and 4) personnel of foreign governments.

Fulbright Grants provide opportunities for faculty members from U.S. universities to teach, study, and conduct research in developing countries and for scholars from developing countries to work in the United States. This program could make a greater contribution to the development and transfer of tropical forest resource expertise. However, the Fulbright program has been cut back sharply in recent years.

AID has given one strengthening grant to a U.S. university to expand its international forestry capability. This is a 5-year matching grant of $100,000 per year with the University of Idaho. There are no plans to award similar grants to other universities in forestry. In comparison, AID has some 50 strengthening grants with U.S. universities in agriculture.

Encouraging Responsible Involvement by Private Corporations

The private sector can be an effective technology transfer agent and could play a more important part in efforts to develop and implement technologies to sustain tropical forests. The U.S. Government has established three programs to increase the involvement of the private sector in fostering development: 1)

Overseas Private Investment Corporation, 2) Trade and Development Program, and 3) International Executive Service Corps. However, none of these programs has been used very much in the forestry sector.

Overseas Private Investment Corporation (OPIC)

OPIC, established in 1971, provides services to U.S. companies interested in investing in the private sector in developing countries. These services include: 1) information on investment opportunities; 2) financial assistance for investment missions, feasibility studies, and market research; 3) insurance for political risks; and 4) loans or loan guarantees. The eligibility criteria for assistance include per capita incomes in the host country; size of the participating business and its degree of involvement in the venture; economic and technical soundness of the proposal; and the contribution of the business to the economy of the host country. Environmental factors are also supposed to be considered. Forestry and biotechnology enterprises can be eligible for OPIC assistance.

Trade and Development Program (TDP)

TDP, established in 1980 under IDCA, aims to increase the exports of goods, services, and technology by U.S. firms to governments in less developed countries. The principal activities of TDP are: 1) sponsoring project identification and feasibility studies, 2) organizing technology workshops, 3) coordinating technical assistance from various U.S. Government agencies to foreign governments, and 4) administering technical training programs in the United States for foreign citizens. The latter two activities are on a reimbursable basis. TDP seeks reimbursement of the costs of feasibility studies from the investors if the project proceeds and it also tries to obtain some cost-sharing by the host countries.

The criteria for selection of TDP activities include: 1) consistency with the development priorities of the host country, 2) availability of funding for project implementation (other than AID), 3) friendliness of the host country to the United States, and 4) export potential of implemented projects.

International Executive Service Corps (IESC)

IESC makes the expertise of volunteer retired executives available to developing countries. IESC gives priority to assistance for small and medium businesses; services to governments are deemphasized. U.S. AID provided $5 million to IESC in fiscal year 1982, slightly over half of its funding. The rest comes from U.S. corporations.

Strengthening Existing Organizations

Foremost among opportunities to strengthen existing development assistance organizations would be to continue and expand support for forestry efforts by AID. AID has a clear mandate from the U.S. Congress to develop and strengthen "the capacity of less developed countries to protect and manage their environment and natural resources" (sec. 118 of the Foreign Assistance Act) with explicit authorization for assistance to "maintain and increase forest resources" (sec. 103b). In 1981, section 118 was further amended to express congressional concern "about the continuing and accelerating alteration, destruction, and loss of tropical forests in developing countries."

AID could emphasize this policy mandate, translating it more often into action. This could include continuing education for AID personnel regarding the relevance of forestry concerns. More project designs could allocate a percentage of funds to relevant environmental protection measures—for instance, water development projects could include components to maintain forest cover on surrounding watersheds. Many of the development activities AID conducts have direct and indirect impacts on tropical forests, and AID does sometimes include forest-related components on projects not specifically aimed at forest development.

Another way AID could enhance its effectiveness in this sphere is through the Food for

Peace program. AID administers some $1.6 billion per year in Public Law 480 Food for Peace activities, but now only about 1 percent of the projects are concerned with forest resources. More of these funds could be directed to reforestation and assuring local involvement in forest and plantation management. Public Law 480 foreign currency reserves could also be used to fund forest research, perhaps including a greater involvement by the U.S. Forest Service.

This redirection of existing efforts is a way to increase U.S. involvement without adding new financing, although substantial increases this way could lead to reductions elsewhere. The international programs of U.S. Government agencies other than AID also could be expanded to play a more active role in sustaining forest resources. The U.S. Fish and Wildlife Service, the Forest Service, and the National Park Service, for instance, have much relevant expertise and could be encouraged to increase their international work.

Research sponsored or financed by the U.S. National Science Foundation (NSF) and the National Academy of Sciences (NAS) has provided important support to AID and other organizations that work to sustain tropical forest resources. These two agencies could be encouraged to intensify their work on important international environment issues.

Another opportunity to strengthen existing organizations concerns the UNESCO Man and the Biosphere (MAB) program. MAB has supported some 1,000 field projects in 90 countries. Nearly one-fourth of its $2 million 1981-83 budget is for activities related to humid tropical zones and MAB has a commendable record of supporting innovative research on tropical forest resources. It has a good international reputation and has been successful in supporting small-scale and pilot project research. UNESCO is the organizing agency for MAB, but each country's effort is funded independently. U.S. support for MAB has been diminishing and much of the U.S. contribution now comes from the Forest Service and the Department of State. The proposed fiscal year 1984 budget contains no funds for MAB.

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Chapter 6

U.S. Tropical Forests: Caribbean and Western Pacific

HIGHLIGHTS

- Past poor land-use practices have degraded forest resources in the U.S. Caribbean and Pacific tropical territories and have resulted in significant amounts of abandoned land and relatively unproductive secondary forest. Related resources (e.g., water supplies and coastal marine resources) are, in many places, threatened by forest loss.
- Although not a problem at present, overexploitation of island forests is likely to occur as populations grow and expectations rise. Much of this could be avoided if forest resource development were integrated with economic development.
- Only Puerto Rico has significant potential for commercial forestry, but both the Pacific and Caribbean territories could provide a greater share of their domestic forest product needs.
- The territorial governments all have designated natural resource agencies and have expressed their recognition of the need to integrate forestry into development, but most of the agencies are small and lack adequate funding and personnel.

INTRODUCTION

Less than 1 percent of the world's tropical forests fall under U.S. jurisdiction. These are located primarily in Puerto Rico, the U.S. Virgin Islands, the U.S. Pacific territories of American Samoa and Micronesia (Guam, the Commonwealth of the Northern Mariana Islands, and the Trust Territory of the Pacific Islands), and Hawaii. Both the Caribbean and Pacific territories have a long history of land-use practices that have created relatively large areas of degraded or abandoned forest land. For over a century, Hawaii has restricted use of its forest areas, primarily to protect their watershed values.

Puerto Rico includes the adjacent small islands. It includes the easternmost islands of the Greater Antilles in the West Indies. It is a mountainous land with a variety of ecosystems. Today, at least one-third of Puerto Rico's 2.2 million acres* is under forest cover, mostly second growth trees, fruit tree plantations, and shade covers in the remaining coffee regions. Despite this, Puerto Rico produces less than 1 percent of its domestic wood requirements (43).

The U.S. Virgin Islands are an unincorporated territory east of Puerto Rico containing about 86,500 acres, including about 50 islands and islets. They have been administered since 1951 by the U.S. Department of the Interior. The three largest islands—St. Croix, St. John, and St. Thomas—are used extensively for tourism and have effectively no forest products industry. However, three-fourths of the island of St. John is the Virgin Island National Park.

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*All land areas in this chapter will appear in acres, as this is the common measurement for U.S. lands. One hectare = 2.47 acres.

Water retention and control, protection of critical marine habitats, and esthetic values are the primary purposes of the forests on these islands.

The U.S. tropical forests in the western Pacific are located in Micronesia and American Samoa. Micronesia includes some 2,000 islands within 3 million square miles in the western Pacific north of the Equator, southwest of Hawaii, and extending west to within 500 miles of the Philippines. They range in size from small, unoccupied coral atolls to large, populated volcanic islands. American Samoa consists of seven islands located south of the Equator. Some wood products are harvested on these islands for local use, although on American Samoa nearly all wood products except fuelwood are imported from nearby independent Western Samoa, and from the United States and New Zealand (5).

Reliable information on the original extent of the forests on the U.S. western Pacific islands does not exist, but forests probably covered most of the island. On many islands—such as Guam, Tinian, and Saipan—man and nature have so changed the islands that it is nearly impossible to identify the original forest types.

The State of Hawaii lies in the middle of the northern Pacific Ocean between Mexico and Micronesia. Hawaii has 8 major islands and 124 smaller islands that cover about 4 million acres. About half this acreage is forest- and shrub-covered.

Since the late 1800's, Hawaii has pursued a policy of protecting its forests for watershed values (16). A well-developed land-use plan was enacted in 1961. All lands were zoned according to allowed use: urban, rural, agricultural, and conservation. Most forested lands are under conservation zoning. Forests on agricultural land can be manipulated, but forests on conservation land cannot without special permission by the Hawaii Board of Land and Natural Resources (9). In 1962, the Hawaii Department of Land and Natural Resources produced the first of three 10-year multiple-use programs for managing water, timber, livestock forage, recreation, and wildlife habitat in the islands' forests.

Industrial forestry recently has become a focus of economic development in Hawaii. There are 47,000 acres of forest plantations in Hawaii, most of which are on public lands (7). However, about 1 million acres have been designated as commercial forest land (areas suitable for growing timber and with some forest cover but not necessarily stocked with timber trees). Of this, the State owns nearly 45 percent. An additional 290,000 acres of extensively grazed lands also are suited for timber crops, but now have no forest cover (16).

Hawaii also hosts a number of organizations dedicated to sustaining tropical forest resources in the islands and the tropical world. For example, an AID-funded project on nitrogen fixation by tropical agricultural legumes (NiFTAL), which produces inoculants on a pilot scale for researchers and legume growers, is based in Hawaii. The East-West Center, created by Congress in 1960 to promote interchange among the United States, Pacific, and Asian countries, is a regional center for discussion and study of natural resource issues. The Pacific Tropical Botanical Garden, the only privately supported tropical botanical garden chartered by the U.S. Congress, is in Hawaii. Forestry research and education are pursued by the University of Hawaii and the Bishop Museum. Hawaii also houses the U.S. Forest Service Institute of Pacific Island Forestry (IPIF), which supports research on forest resources in Hawaii and the U.S. western Pacific, and a cooperative State and Private Forestry division.

In 1979, the U.S. Forest Service and C. Brewer & Co. created the BioEnergy Development Corp., funded by the Department of Energy, to implement and demonstrate IPIF research activities. This joint venture has become one of the largest forestry research and development projects directed at biomass fuel production in the United States. It is cultivating more than 200 acres of fast-growing eucalyptus species on Hawaii Island that will be chipped for use as boilerfuel at two nearby sugar plantation powerplants. Plantings are planned for 400 acres of abandoned sugar cane land and 500 acres of wasteland and undeveloped forest areas (8).

The problems that Hawaii has experienced related to forest resource management (e.g., increased runoff, severe erosion, inadequate water supply) are similar to other tropical forested areas. However, the State is atypical of tropical areas in that its institutional capacity for dealing with these problems is well-developed. Because of this, the expertise and experience embodied in Hawaiian people and organizations working with tropical forest resources can contribute to sustaining tropical forest resources in the U.S. territories and in the developing world.

COMMON CHARACTERISTICS OF ISLAND TROPICAL FORESTS

Island forests share many common features with continental tropical forests, yet display numerous unique ecological and historical attributes. Some characteristics shared by many U.S. Pacific and Caribbean island forests are:

- history of species-richness;
- abundance of endemic (unique, area-specific) species;
- great vulnerability to invasion by exotic plants and animals;
- dependence of water and coastal resources on forests; and
- severe pressure on land resources from human populations.

Species-Rich Forests

Island tropical forests found near continents are rich in tree species (26,48). The 547 native tree species found in Puerto Rico (19,20) approximate the number of tree species found in all the continental United States (18). Some 500 native tree species and several hundred introduced or exotic species grow in the U.S. Virgin Islands (30).

Smaller islands and islands farther from continents have fewer native species, but many exotic species have been introduced to these areas. For example, about 800 tree species were planted in the State of Hawaii between 1908 and 1960 (16). The western Pacific islands have varying numbers of species depending on their distance from Asia and their history of disturbance and replanting.

Abundance of Endemic Species

Many rare species and unique ecosystems have evolved on these islands because of their small size and geographic isolation. Hawaii and the western Pacific islands are especially rich in rare, endemic species; for some tree species only one or two individuals are known (31). In many cases, the insular bird, mammal, and fish life also are endemic. Among the many endangered, endemic species are the Puerto Rican parrot, the Micronesian megapode, and the Yapese fruit bat. In Hawaii, 90 percent of

Photo credit: J. Bauer

Endangered Puerto Rican parrots nesting at artificial nest site; these parrots remain only in the Caribbean National Forest the species in many plant and animal families are endemic and as many as 2,000 plants and animals may be endangered (36).

Local endemism is highly developed in cloud forests. These are, in a sense, islands within islands (28). Cloud forests (also called dwarf or moss forests) occur on steep slopes and hill crests extending into the cloud zone. Thin, leached soil and steep, windswept terrain limit tree growth so trees have a low, bushy appearance, some with bare trunks and branches and broomlike tufted tops. Much is known about cloud forests in Puerto Rico (28), but information on these forests in Micronesia (on Ponape and Kosrae) is meager. This type of forest is very sensitive to disturbances (15).

Island ecosystems provide values to science disproportionate to their small size. Because of the high rates of endemicity, islands provide many species for botanical and zoological investigation. Their clearly defined boundaries facilitate study of species migration, competition, adaptation, and extinction. General principles of evolution can be distilled from island studies and applied to, for example, the design of parks and reserves.

Vulnerability to Invasion by Exotic Plant and Animal Species

The survival of native plants and animals in the U.S. tropical islands is threatened by the conversion of forests to agriculture and urban uses. Introduced plants and animals also pose a great threat because they prey upon or outcompete native species. The result has been a continuing decline in the quality of the forests and a selective elimination of native species.

Photo credit: J. Bauer

Cloud or dwarf forests are important for water retention and as habitat for many endemic species in both Puerto Rico and the U.S. western Pacific islands

Introduction of pigs, goats, cattle, rats, and some birds and insects, affects both the Pacific and Caribbean islands. In the western Pacific islands, for example, introduction of the Rhinoceros beetle contributed greatly to the decline of coconut plantations, and the Giant African snail inhibits nursery production for horticulture and forestry (15,22). In the Caribbean, animals have affected dry ecosystems to a greater degree than moist ecosystems.

Mammals are being introduced to Hawaii by man at 90,000 times the natural rate: one species or population has been successfully introduced every 11 years for the last 200 years. For land birds, the rate is one successful species or population every 4 years. Most of these species are successful at the expense of endemic or indigenous forms (39). Research performed during the 1970's documented the heavy impacts by feral animals on both wet and dry native Hawaiian forests. Results from this research have led to a decision to reduce or eliminate these animals in some areas (17).

Dependence of Water Resources on Forests

On all of the islands, the primary value of forests is their regulation of water regimes. Tropical oceanic islands, except coral atolls, are usually small with steep slopes. The natural freshwater habitat is streams rather than lakes (38). Streams and forests are concentrated in the interior highlands and stream ecology is closely linked with forest ecology. Diversion of water for domestic purposes, plantation agriculture, and industrial needs can leave insufficient waterflow for riverine fauna and flora.

Island ecosystems often host animal populations that depend on local freshwater and forest habitats. Many species spend part of their early lives in the ocean but migrate through streams to complete their lifecycle. In the natural state, much of the stream where they live and migrate lies within the forest. But when forests are altered or removed, stream habitats change. Any uninhabitable stretch can destroy a population that must migrate through it to reach its normal adult habitat upstream (38).

Photo credit: J. Bauer

La Mina Falls: Regulation of water regimes is the most important function of forests on tropical high islands. Most upper watersheds have steep slopes and should remain forest-covered to reduce erosion and siltation of reservoirs and coastal ecosystems

On many islands, deforestation has resulted in turbid, erratic, and seasonally disappearing streams (11). For example, the U.S. Virgin Islands have no remaining permanent streams (30). Aquifer water levels are declining as populations pump out more than is recharged. Because of inadequate freshwater resources, water in the U.S. Virgin Islands is expensive, ranging from $10 per 1,000 gallons from a desalination plant to as much as $12 per 1,000 gallons for water barged in from Puerto Rico (32).

Dependence of Coastal Ecosystems on Forests

Disruption of water regimes in tropical islands has considerable influence on coastal marine environments. When forested watersheds are cleared, waterflow and erosion accelerate, depositing a blanket of sediment on coral reefs. This deprives corals of light and oxygen and causes the bottom to become soft and unstable, thereby preventing recolonization. The addition of large amounts of freshwater runoff also is damaging because corals can only live within a limited salinity range (29).

Normally, mangrove forests along the coastline act to filter and chemically buffer the sediments. Seagrass meadows also can filter sediment that escapes the mangroves. Unfortunately, little is known about how these filtering and silt-adjusted biotic communities operate, how they are affected by and affect the nutritional levels of lagoon and reef waters, or how they affect fish nurseries and the coral reef community.

The approximately 31,000 acres of mangroves in the U.S. Micronesian territories provide food and building materials for local people and are important to traditional Micronesian life. Mangroves also are found along the coastlines of American Samoa, Hawaii, and the U.S. Caribbean islands. Here, too, they are the spawning grounds and nurseries for many forms of marine and reef life. Coral reefs, protected by mangroves, are basic in the food chain of shallow waters, affecting fish and other marine resources of both subsistence and commercial importance to island people of the U.S. tropical territories (23). Reefs have economic importance not only from their food production and tourist value but also as a basis for industry built around scientific research (6).

Photo credit: E. Petteys

Coastal mangrove forests capture, filter, and chemically buffer sediments from runoff. Little is known about the operation and carrying capacity of these communities and their relation to fish nurseries and the coral reef community

Vulnerability to Land Degradation

Because of small land areas, rapidly growing populations, and transportation barriers, appropriate land-use is especially important for island development. Lacking enough land for shifting cultivation, indigenous peoples on small tropical islands developed land-intensive systems of agriculture. Small-plot land-use systems were common in both the U.S. western Pacific and Puerto Rico. Today, these agricultural systems can no longer support the growing populations. Because of limited land, farmers displaced by residential or commercial construction move to the more easily eroded island hillsides, and roads may be routed through susceptible mangrove forests (6).

U.S. CARIBBEAN TERRITORIES: PUERTO RICO AND THE U.S. VIRGIN ISLANDS

Forest Resources: Status and Trends

Puerto Rico

Puerto Rico's total land area, including that of adjacent small islands, is 2,198,000 acres. Originally, most of Puerto Rico was forested, but agricultural colonization reduced forest cover to only 9 percent by 1950—4 percent government forests and 5 percent privately owned forests. Today, at least one-third of Puerto Rico is again under forest cover, mostly second growth trees, fruit tree plantations, and shade cover in the remaining coffee regions. Original forest cover is found only in a few inaccessible regions. Some 98,000 acres are public forest, divided between Federal and Commonwealth administration. Abandonment of coffee plantations and farmlands, particularly on steep slopes, released 1.1 million acres now potentially available for forestry activities.

Some of this land is probably too steep to use, although some recreation and gathering activities might be allowed. Some acreage will be required for future development; nevertheless, a considerable amount of land could be used for productive forestry. Some 200,000 acres are estimated suitable for commercial forestry (42, 44) and some could be used for forestry-agriculture combinations.

Pronounced differences in natural vegetation occur because of sharp variations in altitude, climate, and soil characteristics. Using the Holdridge Life Zone system, six zones are found in Puerto Rico (12). At least 98 percent of the land area is covered by three of the life zones (table 17). The other three are found only at or near mountaintops and are very wet. Generally, they are unproductive for agricultural or forest crops and still exist in their natural state. Most of these lands are in public forests and are important for watershed protection.

Table 17.—Life Zones and Area in Puerto Rico

Life zone	Total acres	Percent of total
Subtropical moist forest	1,314,582	59.2
Subtropical wet forest	524,830	23.6
Subtropical dry forest	346,936	15.6
Subtropical lower montane forest ..	26,950	1.2
Subtropical rain forest	3,260	0.1
Subtropical lower montane rain forest	3,040	0.1

SOURCE: Adapted from: J. J. Ewel and J. L. Whitmore, *The Ecological Life Zones of Puerto Rico and the U.S. Virgin Islands*, USDA Forest Service Research Paper ITF-18, 1973. *In:* Schmidt, 1982, and S. I. Somberg, *Virgin Islands Forestry Research: A Problem Analysis* (St. Croix: College of the Virgin Islands, Virgin Islands Agricultural Experiment Station, 1976).

Subtropical dry forests support a forest cover rich in tree species, but they do not have good potential for commercial forest production. In Puerto Rico and throughout the Tropics, dry forests often are converted to grazing land (fig. 18). The southern coastal plain of Puerto Rico and associated small islands contain most of the dry forests, limiting the potential for commercial forestry and increasing their need for effective conservation programs.

The subtropical moist life zone, with 1,000 to 2,000 mm of rainfall per year, covers most of Puerto Rico. Agriculture, urban, and industrial uses are common in this zone. Subtropical wet forests are found higher in the mountains of Puerto Rico where rainfall is above 2,000 mm. Pasture is common in this zone, which is cooler, and coffee, bananas, plantains, and other fruits grow well.*

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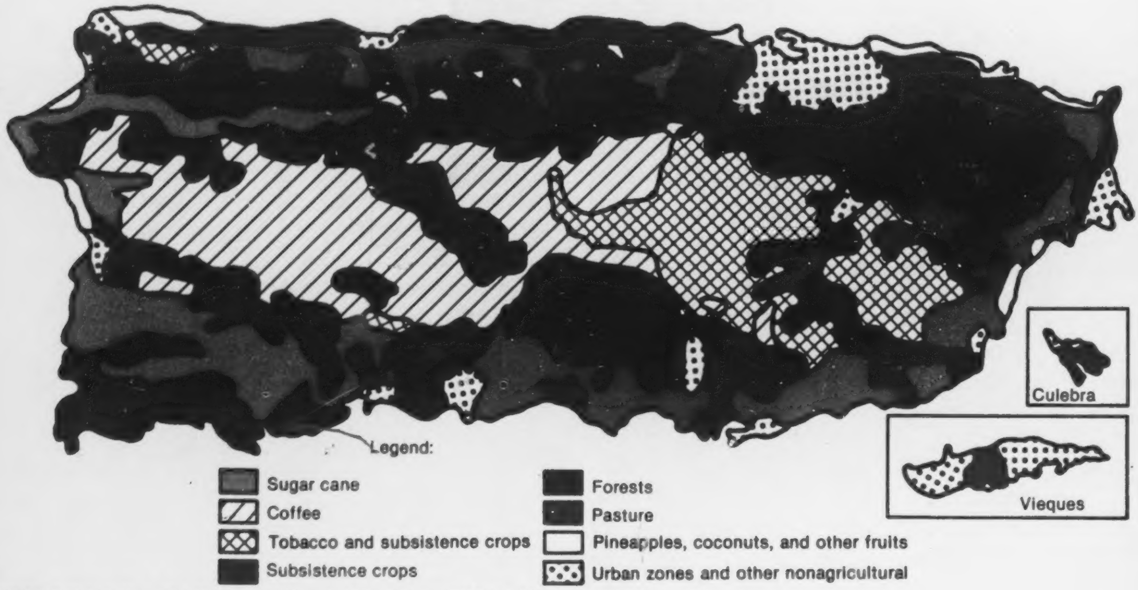
*Ewel and Whitmore (12) provide more detailed descriptions of all life zones in Puerto Rico and the U.S. Virgin Islands.

Figure 18.—Land Use in Puerto Rico


Culebra
Vieques
Legend:
Sugar cane
Coffee
Tobacco and subsistence crops
Subsistence crops
Forests
Pasture
Pineapples, coconuts, and other fruits
Urban zones and other nonagricultural

SOURCE: Rafael Pico, *The Geography of Puerto Rico* (Chicago: Aldine Publishing Co., 1974), p. 360.

This wet forest life zone presents a substantial management challenge. Forests composed of abandoned coffee shade trees, in particular, contain some commercially valuable trees, but most of their volume is in three legumes (*Inga vera, I. laurina,* and *Erythrina poeppingiana*) and other marginally valuable species (e.g., *Guarea guidonia*) (2). These forests supply little useful timber, but they offer excellent watershed and soil protection, wildlife habitat, and recreational and esthetic opportunities.

U.S. Virgin Islands

The U.S. Virgin Islands are part of the Lesser Antilles Archipelago. Its three largest islands are St. Thomas (17,000 acres), St. John Island (15,000 acres), and St. Croix (55,000 acres). Only two Holdridge ecological life zones are found in the U.S. Virgin Islands: subtropical dry forests and subtropical moist forests (table 18). The subtropical dry forest zone occupies almost three-fourths of the islands' land. There are no permanent rivers or streams in the U.S. Virgin Islands outside the Virgin Islands National Park. All water retained in aquifers comes from rainfall (30); these are depleted and many wells are dry. Despite the high costs of desalinating water or importing it from Puerto Rico by barge, little attempt has been made to institute a revegetation program to increase water retention and to prevent the flooding and marine siltation (32).

Table 18.—Life Zones of the U.S. Virgin Islands

Island	Square miles	Acres	Subtropical dry forests (acres)	Subtropical moist forests (acres)	Percent of total area
St. Croix	84	54,563	45,469	9,094	63.9
St. Thomas	28	17,984	7,001	10,983	21.1
St. John	20	12,835	8,214	4,621	15.0
Total	132	85,382	60,684	24,698	—
Percent of total			71.1	28.9	100.0

SOURCE: S. I. Somberg, *Virgin Islands Forestry Research: A Problem Analysis* (St. Croix: College of the Virgin Islands, Virgin Islands Agricultural Experiment Station, 1976).

These islands were once largely forest covered (fig. 19). Less data are available on forest use and potential in the U.S. Virgin Islands than for Puerto Rico. However, an estimated 35,300 acres of forest and brushland exist, including 5,000 acres of commercial forests and 15,800 acres of noncommercial forests. The remaining 14,500 acres are unclassified and are mountainous. Most of the forested area outside the Virgin Islands National Park is in private ownership (30).

The majority of land considered suitable for agriculture (including forestry) is on St. Croix. Two high-value timber species, mahogany and teak, are grown at the U.S. Forest Service Estate Thomas Experimental Forest on that island. Teak can be established on marginal land common in central St. Croix and has proved compatible with grazing.

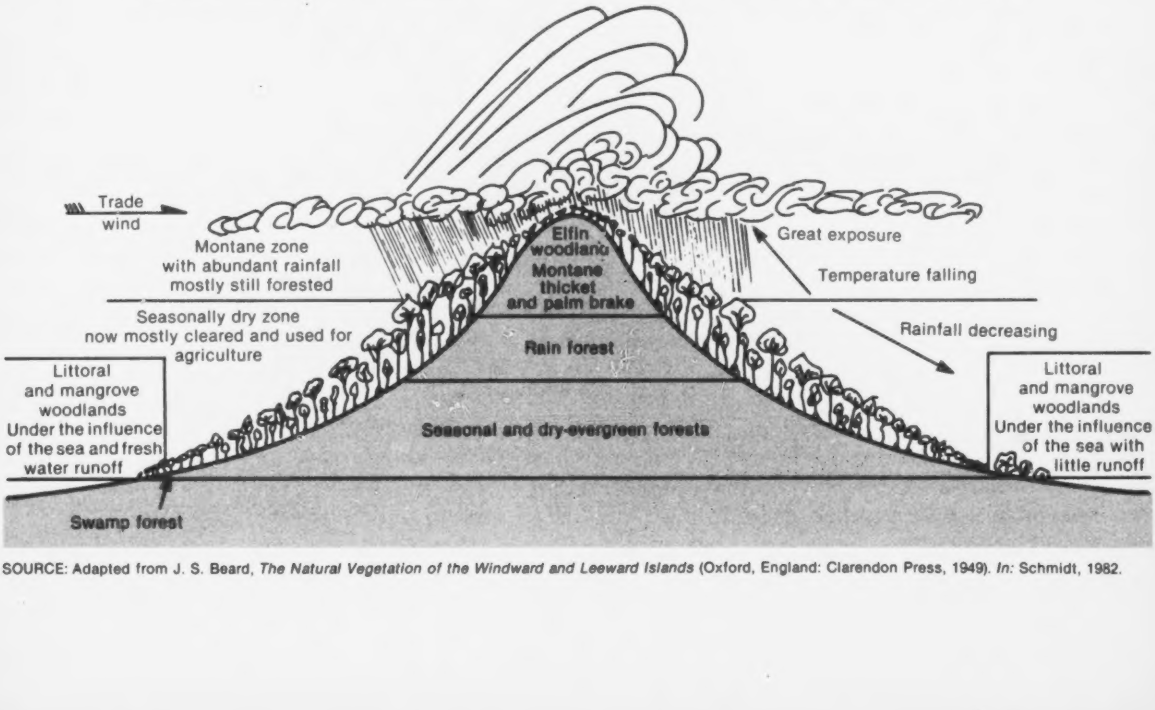
A combination of high land prices, competing land uses, and certain adverse soil and topography factors probably preclude most commercial forestry on the U.S. Virgin Islands (30). However, potentials exist for agricultural tree crops (e.g., coconut, mango, limes), management of watershed forests, and roadside and urban forestry.

History of Forest Use

Puerto Rico and the U.S. Virgin Islands share a similar forest-use history. Essentially all of Puerto Rico was forested on the arrival of Columbus in 1493 (fig. 20). Then agricultural and urban expansion into the forests gradually took place. Until the early 20th century, most wood harvested was used for fuel or construction, but construction wood was being imported as early as the 1700's. The only exports were rare and valuable native species such as lignumvitae and satinwood (*Guaiacum officinale* and *Zanthoxylum flavum*). The economic depression in the 1930's, combined with increased population, had heavy adverse impacts on Puerto Rico. Agriculture was pushed farther up the hills across the island. By 1935, only about 2 percent of the land area—the most inaccessible and infertile areas—had not been deforested at some time.

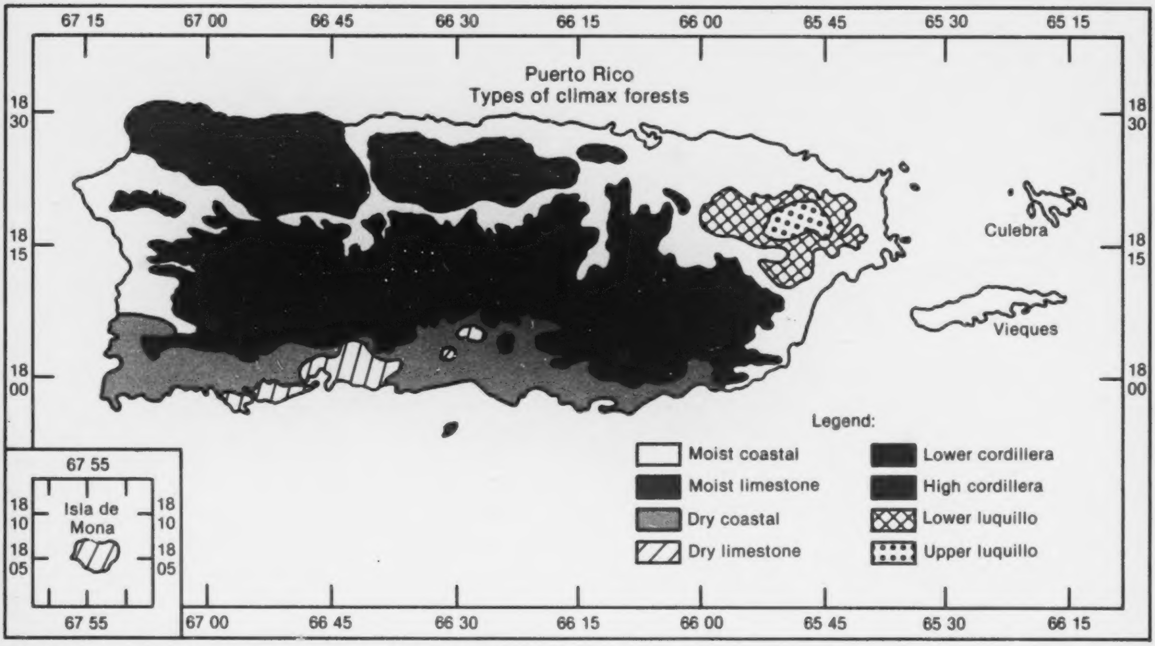
In the 1920's and 1930's, the Federal Government acquired about 50,000 acres of mountain land in Puerto Rico for forest and watershed

Figure 19.—An Idealized Transect Through a Caribbean Island in the Lesser Antilles


Trade wind
Montane zone with abundant rainfall mostly still forested
Elfin woodland
Montane thicket and palm brake
Great exposure
Temperature falling
Seasonally dry zone now mostly cleared and used for agriculture
Rainfall decreasing
Rain forest
Littoral and mangrove woodlands Under the influence of the sea and fresh water runoff
Seasonal and dry-evergreen forests
Littoral and mangrove woodlands Under the influence of the sea with little runoff
Swamp forest

SOURCE: Adapted from J. S. Beard, *The Natural Vegetation of the Windward and Leeward Islands* (Oxford, England: Clarendon Press, 1949). *In:* Schmidt, 1982.

Figure 20.—Original Vegetation of Puerto Rico


67 15
67 00
66 45
66 30
66 15
66 00
65 45
65 30
65 15
18 30
18 15
18 00
Puerto Rico
Types of climax forests
Culebra
Vieques
67 55
Isla de Mona
18 10
18 05
Legend:
Moist coastal
Moist limestone
Dry coastal
Dry limestone
Lower cordillera
High cordillera
Lower luquillo
Upper luquillo

SOURCE: Rafael Pico, *The Geography of Puerto Rico* (Chicago: Aldine Publishing Co., 1974), p. 180.

protection. In the late 1930's and early 1940's, the Civilian Conservation Corps planted some 25,000 acres of timber trees that survive today, mostly in public forests. Today 100,000 acres are in public forest lands, divided between Federal and Commonwealth administration. Caribbean pine (*Pinus caribaea* var. *hondurensis*) was first established on the island in 1962. Through the 1960's and 1970's, from 100 to 500 acres per year of timber trees, mostly pine, were established on private lands. About 200 acres per year of various species were planted on public forest lands.

Planting records of the Institute of Tropical Forestry indicate that 95,000 acres of trees have been planted in Puerto Rico (2), but no forest plantation inventory has been conducted. The 1973 land-use inventory (10) and the 1980 forest resources survey (2) indicated that there are 800,000 acres of secondary forest in Puerto Rico. About half of Puerto Rico consists of land abandoned from farming or grazing.

The Natural Resource Inventory performed by the U.S. Department of Agriculture in 1977 estimated average annual soil loss for different land uses in the Caribbean (Puerto Rico and the U.S. Virgin Islands), all of which are considerably higher than the average annual soil loss for the United States (table 19). These erosion rates reflect the extensive historical deforestation of the islands and the continuing cultivation and inadequately managed grazing of lands unsuitable for permanent agriculture.

Table 19.—Average Annual Sheet and Rill Erosion in the U.S Carribbean (tons/acre)

Land use	U.S. Caribbean average	U.S. average
Cropland	49	5.1
Rangeland	50	2.8
Forest land:		
Grazed	6	3.9
Not grazed	10	0.6

SOURCE: Adapted from USDA, 1977 Natural Resources Inventory, Washington, D.C.

Geoclimatic Regions in Puerto Rico

Five basic rock types are present in Puerto Rico. Composition within each rock type varies and there are hundreds of soil types (3,21). However, changes in forest growth and composition are noticeable only across the major rock types. These five rock types can be overlayed with Holdridge Life Zones to form 17 geoclimatic regions (14). The regions with potential for commercial forestry use include:

- ***Moist-alluvial region.*—This is the zone of mechanized agriculture, urban development, and protected coastal mangroves and wetlands. These uses are considered higher priority than forestry and probably will preclude it in this zone in the future.**
- ***Moist-volcanic region.*—This extensive zone is very important for forest development. It is a prime zone for growing Caribbean pine, mahogany, teak, blue mahoe, and eucalyptus. Where soils are poor, degraded, or on moderately steep slopes, agricultural practices have ceased. Native pastures, especially where ferns invade, can be of very low productivity. Regenerated native forests can be developed for conservation or timber production. However, most abandoned land in this region is deforested and is not regenerating into secondary forests of native species (27).**
- ***Moist-limestone region.*—This is an area of extensive agricultural abandonment in northwestern Puerto Rico. Mahogany, teak, and *Eucalyptus deglupta* grow well on the lower slopes of the rounded hills of this region; blue mahoe (*Hibiscus elatus*) grows well in moist valley bottoms. Well-managed plantations of these species are grown in three Commonwealth forests in this zone.**
- ***Moist-granodioritic region.*—Large areas of abandoned farms are common throughout this region. Caribbean pine is one tree species that thrives on these deep, infertile sands.**
- ***Moist and wet serpentine region.*—This region in southwestern Puerto Rico has shallow soils that are low in nitrogen and phosphorus and very permeable. Agriculture fails on these lands and tree growth is slow (45). Two Commonwealth forests covering 17,300 acres located in the region contain important watersheds. Some areas can support plantations of Caribbean pine, maria (*Calophyllum calaba*), and, with heavy fertilizers, avocados.**
- ***Wet-volcanic region.*—Most of the wet life zone in Puerto Rico is found over volcanic soil and the main crop is coffee. In the late 1960's and early 1970's, many coffee plantations were left untended due to a shortage of laborers, and shrubs and trees invaded. From the late 1970's to the present, the coffee crop area has again expanded, apparently because of a shadeless coffee production system that uses nets for harvest (41) and a $2 million incentive program offering up to $1,000 per acre for coffee planting. Since the new production is more intensive, considerable areas of abandoned coffee shade still exist.**

In 1981, Puerto Rico produced about 100,000 board feet of hardwood timber with a retail value of about $200,000, while the island's imports of forest products totaled $410 million. Softwoods were imported largely from Canada and the United States, and hardwoods derived primarily from the United States and Brazil (table 20). The growth in forest product imports, now increasing by $25 million per year, has been rapid over the past 40 years: 1940—$5 million to $8 million, 1950—$20 million, 1970—$144 million (27).

Forest cover in Puerto Rico has increased from 9 percent in 1950 to 40 percent of the total area today because of a complex set of social, economic, and cultural factors. Agricultural exploitation of tropical lands is often cyclical. Lands of marginal agricultural productivity are exhausted by cropping, then abandoned to nat-

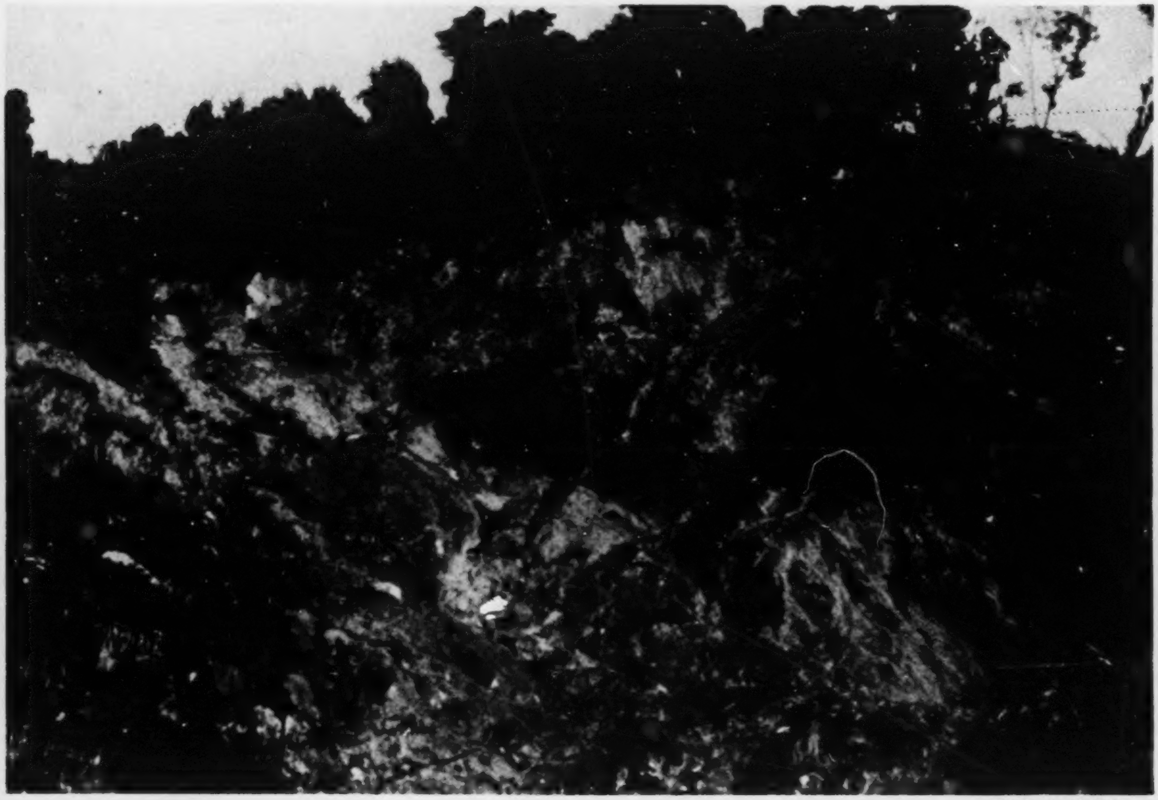


Photo credit: J. Bauer

Landslides, such as this one in the Caribbean National Forest, are a common sight because of the high rates of erosion reflecting inappropriate hillside construction, historical deforestation, and continuing cultivation of lands unsuitable for permanent agriculture

ural succession. If and when some measure of fertility is restored, the lands may be cleared and cropped again. A peak of agricultural activity in Puerto Rico in the 1930's and 1940's severely degraded the productivity of large areas of land and led to their abandonment.

In both Puerto Rico and the U.S. Virgin Islands, the abandonment of the sugar cane industry decreased the amount of land under cultivation and some of this has reverted to brush. Brush and nonwoody species associated with forest and brush lands are important for soil and water management and have esthetic importance to the tourism industry in the drier areas of the Caribbean.

Beginning in the 1950's, industrial development led to more attractive employment opportunities in industry than in agriculture, lower priority for agricultural programs, and increased abandonment of land from farming. The growth of tourism also attracted capital and labor away from agriculture. Complementing the increased availability of alternative employment were easy air transportation to the mainland United States and social support programs (e.g., food stamps) offered by the Federal Government. Thus, the need to scratch out a meager living on steep infertile slopes was greatly reduced. These activities continue to reduce dependence on marginal agricultural activities.

Table 20.—1981 Lumber Imports Into Puerto Rico by Species and Country of Origin

		Totals	
Species	Country	Quantity (MBF)	Wholesale dollar value
Softwoods:			
Cedar (other)	Canada	599	$ 144,000
	United States	468	149,000
Douglas fir	Canada	6,733	1,330,000
	United States	764	357,000
Hemlock	Canada	30,544	5,973,000
	United States	31	15,000
Pine	Canada	1,928	391,000
	Honduras	1,240	336,000
	United States (Southern Ponderosa White)	31,986	10,770,000
Redwood	United States	220	314,000
Spruce	Canada	7,548	1,212,000
Western red cedar	Canada	535	179,000
Other softwoods	United States	765	666,000
	Brazil	39	12,000
	Colombia	51	3,000
Subtotal		83,451	$21,851,000
Hardwoods:			
Mahogany	Brazil	3,261	2,096,000
Maple	United States	1,417	815,000
Spanish cedar	Brazil	260	87,000
	Colombia	291	55,000
	Honduras	98	95,000
	Surinam	10	5,000
Walnut	United States	42	35,000
White oak	United States	2,075	478,000
Other hardwoods	Brazil	1,255	731,000
	Colombia	459	117,000
	French Guiana	64	10,000
	Malaysia	23	15,000
	United States	1,829	1,349,000
Subtotal		11,084	$ 5,888,000
Total		94,535	$27,739,000

SOURCE: R. C. Schmidt, "Forestry: Puerto Rico and the Virgin Islands," OTA commissioned paper, 1982.

In addition, the price of rural land has long since come to reflect scarcity rather than productivity. Forest land in Puerto Rico may cost $1,000 to $2,000 per acre, and land values in the U.S. Virgin Islands have exceeded $10,000 per acre. Consequently, land speculation is common and much land lies idle awaiting development. Puerto Rico maintains a law against private individuals or corporations owning more than 500 acres and, in general, the land is in small holdings. Nearly 90 percent of the land ownerships are less than 48 acres (33).

The potential for plantation forestry in Puerto Rico has been greatly increased as lands previously used for agriculture have become available. Also, natural secondary forest may supply useful forest products in the future. However, the total volume of wood in the secondary forest in Puerto Rico is not great—22 cubic meters per acre (m^3/acre) in abandoned coffee plantations and 18 m^3/acre in secondary forests (2). Undisturbed moist tropical forests often support more than 80 m^3 of wood per acre.

Trends in the growth of forest area or volume are not yet known. In 1980, field work was done for the first comprehensive inventory of Puerto Rico's forests, and future inventories in 1985 and 1990 will begin to show trends. Observations indicate that forest area is increasing slightly or is stabilized (27). The only cutting occurring in these secondary forests is for fence posts, which probably does not decrease overall volume growth significantly.

Organizations Dealing With Tropical Forests

Although several Commonwealth and Federal agencies are involved in tree planting in Puerto Rico and the U.S. Virgin Islands, the U.S. Forest Service, the Virgin Islands Department of Agriculture (VIDA), and the Puerto Rico Department of Natural Resources (DNR) are the agencies with primary responsibility for forestry (table 21). U.S. Forest Service activities include research at the Institute of Tropical Forestry (ITF), administration of the Caribbean National Forest, and cooperative programs with the DNR and VIDA.

ITF uses the Luquillo Experimental Forest, several Commonwealth forests, and the 120-acre Estate Thomas Experimental Forest in the Virgin Islands as sites for research. Even though timber management has been ITF's main research objective, cooperative programs have been under way with AID, the Peace Corps, U.S. Fish and Wildlife Service, and several universities and Caribbean nation governments.

Neither the land grant University of Puerto Rico nor the College of the Virgin Islands has a forestry curriculum or an integrated natural resource management curriculum. The Virgin Islands Department of Agriculture's Forestry Program, with five staff members, operates a nursery, an urban forestry program, and a rural reforestation program. Nearly 400 acres have been reforested since the program's inception in 1967.

Changing public attitudes toward Puerto Rico's forests is the primary focus of DNR's Forest Service. It has begun a media campaign, trained field agents in each of the five regions of Puerto Rico, and recently embarked on a program to bring private landowners into commercial forestry. State and private forestry programs administered by the U.S. Forest Service provide technical assistance to guide the DNR Forest Service's forest management, utilization, and extension programs.

Table 21.—Organizations Dealing With Tropical Forests in Puerto Rico and the U.S. Virgin Islands

Agency/Responsibilities

Federal Government:

- *Forest Service:* Administers the Caribbean National Forest, participates in the Cooperative Forest Management Act, and conducts research in forest management, recreation, wildlife, and tropical tree culture.
- *Soil Conservation Service:* Advises landowners about land-use alternatives, including forestry practices.
- *Agricultural Stabilization and Conservation Service:* Approves incentive applications for forestry practices included under the Rural Environmental Assistance Program Act.
- *Agricultural Extension Service:* Handles island-wide education campaign promoting tree-planting for ornamental, recreational, environmental, and commercial purposes.
- *Mayaguez Institute of Tropical Agriculture:* USDA agricultural research station specializing in developing and testing crops suited for tropical areas including fruit trees and cacao.
- *National Park Service:* Administers San Juan National Historic Site, Puerto Rico; Virgin Islands National Park, St. John; Buck Island Reef National Monument, St. Croix; Christianstead National Historic Site, St. Croix.
- *Federal Highway Authority:* Develops specifications regulating tree planting along roads built with Federal funds.

Commonwealth and Territory Governments:

- *Forest Service, Department of Natural Resources, Puerto Rico:* Manages the 13 Commonwealth forests for watershed, recreation, research, wildlife, and timber. Under the Cooperative Forest Management Act, conducts field work related to private reforestation programs. Produces and distributes seedlings from three nurseries.
- *Agricultural Services Administration, Puerto Rico:* Grows forest, ornamental, fruit, and shade tree seedlings at the Monterrey Nursery in Dorado, Puerto Rico.
- *Forestry Program, Department of Agriculture, U.S. Virgin Islands:* Operates a nursery, manages urban forestry on public lands, and runs a rural reforestation program for private landowners.
- *Department of Conservation and Cultural Affairs, U.S. Virgin Islands:* Administers territorial parks, Earth Change Permit System restrictions on earth-moving, and Sediment Reduction Program managing watersheds related to marine sedimentation.

Universities and colleges:

- *University of Puerto Rico:* Offers undergraduate and graduate programs in biology, ecology, agronomy, and administers system of agricultural experiment stations.
- *College of the Virgin Islands:* Offers undergraduate programs in biology and chemistry and administers the Virgin Islands Experiment Station which maintains Forest Service experimental plots.

SOURCE: Adapted from L. H. Liegel, "Woodland Conservation in Puerto Rico: Its Past, Present, and Future," New York College of Environmental Science and Forestry, Syracuse, N.Y., thesis, 1973.

U.S. PACIFIC TERRITORIES: AMERICAN SAMOA, TRUST TERRITORY OF THE PACIFIC ISLANDS, COMMONWEALTH OF THE NORTHERN MARIANA ISLANDS, AND GUAM

American Samoa is the only U.S. territory that lies south of the Equator. The Trust Territory of the Pacific Islands, Commonwealth of the Northern Mariana Islands, and Territory of Guam constitute most of Micronesia,* which lies north of the Equator between Hawaii and the Philippines (fig. 21). Micronesia covers an area of the western Pacific roughly equivalent to that of the conterminous United States (3 million square miles) embracing some 2,000 islands lying in three major archipelagoes: the Marianas, the Carolines, and the Marshalls (fig. 22).

American Samoa and Guam are unincorporated territories (to which the U.S. Constitution has not been expressly extended) under the administration of elected Governors. American Samoa has been administered by the United States since 1900 and by a Governor appointed by the Secretary of the Department of the Interior specifically since 1951. Although relations between the government of Guam and the Federal Government also are conducted under the jurisdiction of the Department of the Interior, residents of Guam elect their own officials.

The Trust Territory of the Pacific Islands (TTPI), which originally included the Northern Mariana Islands, was established under U.N. sanction after World War II. Administration of the Trust Territory has been the responsibility of the Department of the Interior through an organization composed of the High Commissioner and District Adminstrators. TTPI is treated as domestic except that the Peace Corps has special congressional authorization to operate there.

Under an executive order signed by President Ford, each district was given the opportunity to determine its own form of government and degree of independence from the United States. The Commonwealth of the Northern Mariana Islands was established and separated from the Trust Territory in 1978, although some relations between the Marianas and the U.S. Government continue under the jurisdiction of the Department of the Interior. The remaining polical entities—the Republic of Palau, the Federated States of Micronesia (Yap, Truk, Ponape, and Kosrae), and the Republic of the Marshall Islands—now must decide whether or not to become nations in free association with the United Staes. Free association would allow them free control of internal affairs while assuring them fiscal aid and national defense provisions from the United States.

By January 1981, each emerging nation had installed a constitutional government with democratically elected officials (table 22). All of these provisional entities are weak economically and have existed almost entirely on Federal funding since World War II. U.S. appropriations for the Trust Territory, excluding Federal categorical programs, exceeded $100 million in fiscal year 1980 (40). The government employs 56 percent of the work force, and provides 76 percent of the wages (37).

Forest Resources: Status and Trends

Considerable differences exist in the topography among the islands. Some are rugged, high islands, some with active volcanoes, while others are low islands and coral atolls.

The original vegetation of the high volcanic islands included rain forests on the windward slopes, and drier forests on the leeward slopes. On some of these islands, grass or fern savanna naturally occurred. The natural cover of elevated coral limestone areas is dense forest with species composition different from the high volcanic type. High coral islands are floristically much richer than the forests of low

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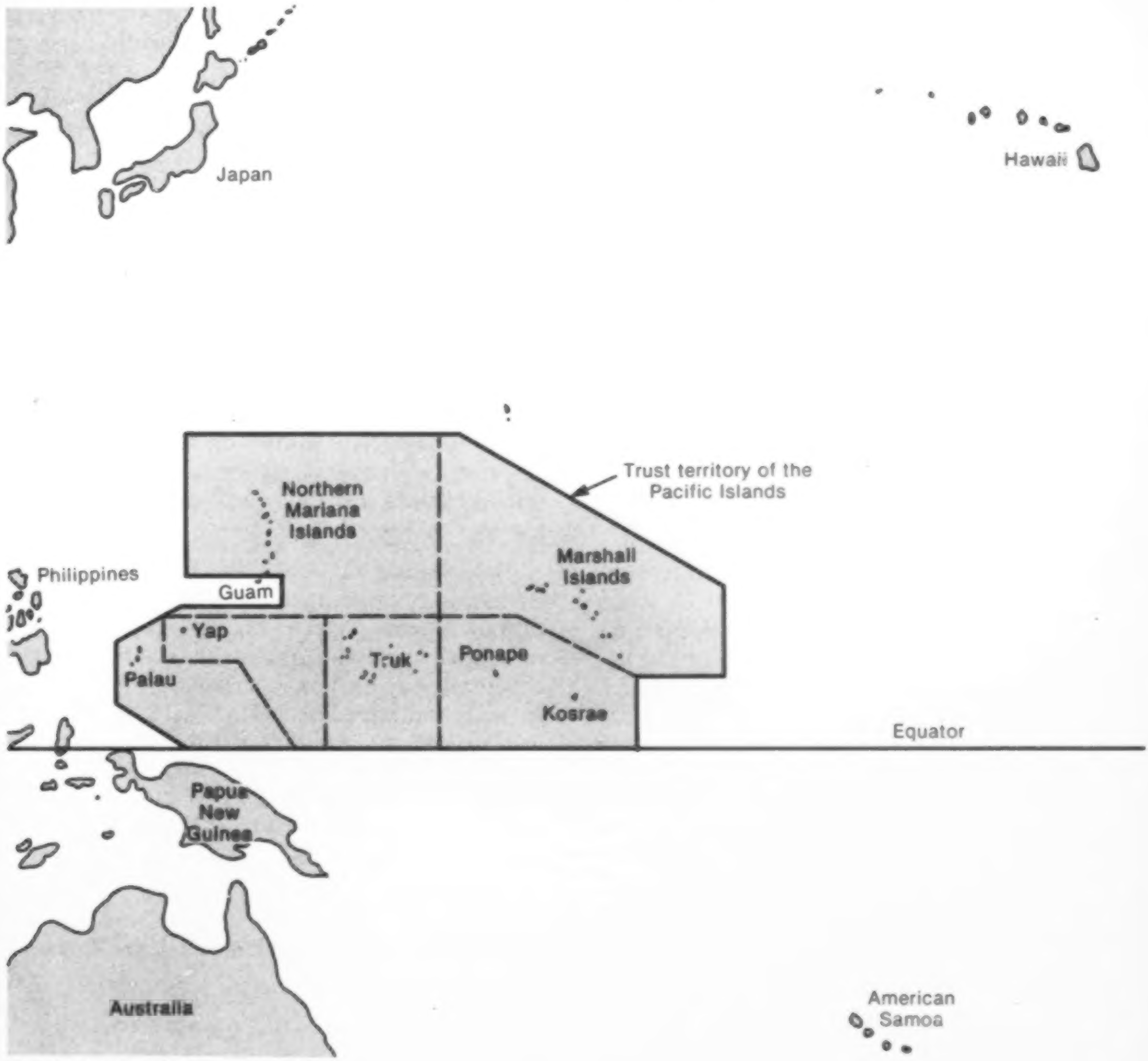
*Other islands in Micronesia are Wake, Marcus, Volcano, Bonin, Nauru, and Kiribati.

Figure 21.—Location of the U.S. Western Pacific Territories

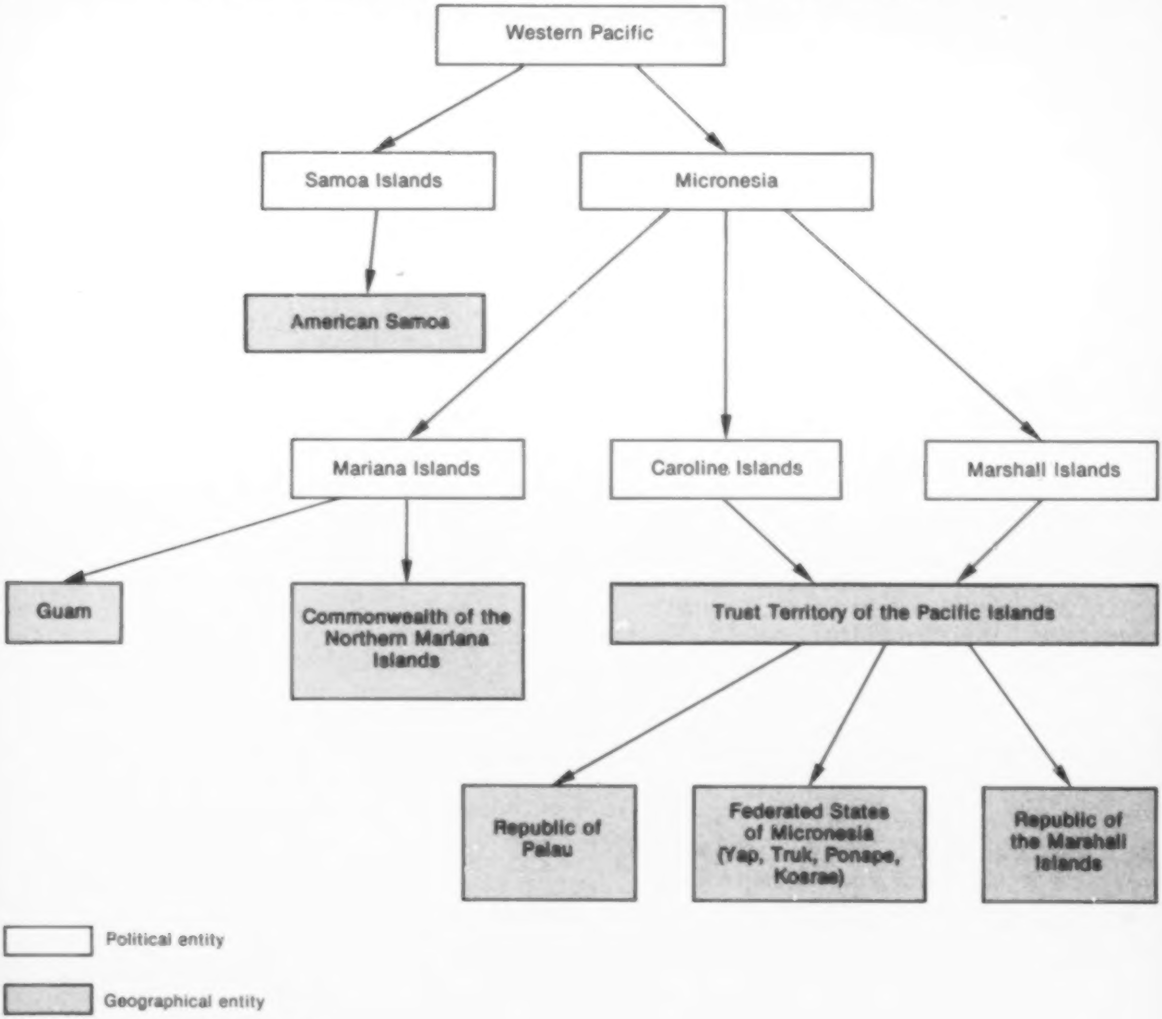

Japan
Hawaii
Northern Mariana Islands
Trust territory of the Pacific Islands
Philippines
Guam
Marshall Islands
Yap
Palau
Truk
Ponape
Kosrae
Equator
Papua New Guinea
Australia
American Samoa

SOURCE: Office of Technology Assessment.

coral islands. Even an elevation change of a few feet results in a much richer flora. The natural vegetation of low coral islands is a "beach" type, adapted to highly saline water and soils. Some of the drier islands have little more than coconuts, scrub, and bunch-grass savanna, or salt flats.

The current extent and condition of forests in the U.S. Pacific vary greatly from one island to the next. A long history of disturbance by man and natural forces left little undisturbed forest. A decline in agricultural production for export, plus urban migration and dependence on U.S. Federal income supports and imported

Figure 22.—Geopolitical Breakdown of the U.S. Western Pacific Territories


Western Pacific
Samoa Islands
Micronesia
American Samoa
Mariana Islands
Caroline Islands
Marshall Islands
Guam
Commonwealth of the Northern Mariana Islands
Trust Territory of the Pacific Islands
Republic of Palau
Federated States of Micronesia (Yap, Truk, Ponape, Kosrae)
Republic of the Marshall Islands
Political entity
Geographical entity

SOURCE: Office of Technology Assessment.

products are probably the reasons why agriculture has lost prominence. Most abandoned agricultural land naturally revegetates to savanna or to secondary forest. Little of the secondary forest is suitable for commercial timber exploitation due to poor quality and low volume of commercial tree species.

Timber exploitation has declined since World War II. Much of the choice timber had been cut by 1950. Most of the islands could sustain forest production to help meet local needs, although there is little potential for export. Rapidly increasing populations will consume any available forest products produced within short land or sea hauls.

American Samoa

American Samoa is comprised of the seven eastern islands of the Samoan group, with a total land area of about 50,000 acres. Two

Table 22.—Pacific Territories of the United States

Territory or island	Approximate number of islands[a]	Dryland (acres)	1980 population	Current (C) or projected (P) relationship with the United States
American Samoa	7	49,200	32,400	Unincorporated territory (C)
Guam	1	135,000	105,000	Unincorporated territory (C)
Commonwealth of the Northern Mariana Islands	21	76,000	16,900	Commonwealth of the United States (C) (established 1978)
Trust Territory of the Pacific Islands (except Northern Mariana Islands)	2,182	291,340	116,345	—
Federated States of Micronesia	607	165,095	73,500	Free association, U.S. funded (P)
Kosrae	5	26,270	5,500	—
Ponape	165	90,000	22,300	—
Truk	290	20,950	37,500	—
Yap	149	27,875	8,200	—
Republic of the Marshall Islands	1,225	17,945	31,045[b]	Free association, U.S. funded (P)
Republic of Palau	350	108,300	11,800	Free association, U.S. funded (P)
Total	2,211	551,540	275,645	—

[a] Sources: American Samoa Government, *American Samoa's Annual Report, Fiscal Year 1980* (Pago Pago: Office of Samoan Information, 1981); Government of Guam, *Annual Report FY 1980, Territory of Guam*, Office of the Governor of Guam, 1981; U.S. Department of State, *Trust Territory of the Pacific Islands*, 1980, Report to the United Nations on the Administration of the Trust Territory of the Pacific Islands, Washington, D.C., 1981.

[b] 1980 population figure from Department of State.

SOURCE: C. D. Whitesell, C. W. Philpot, and M. C. V. Falanruw, "Congressional Action to Improve the Sustainability of U.S. Tropical Forest Resources in the Pacific," OTA commissioned paper, 1982.

islands are coral atolls, whereas the others rise steeply from the sea. Tutuila Island, with a land area of 34,000 acres, has approximately 90 percent of the population. It has one flat coastal plain of about 3,200 acres where urban growth is concentrated. Outside of Tutuila, the economy is classified as subsistence. At least 95 percent of American Samoa is communally owned (25) and land disputes are common.

Through massive infusion of Federal money from the United States, American Samoa has in recent years developed a cash economy. This has resulted in less land used for cultivation and subsistence. Most land in American Samoa is classified as undeveloped (table 23).

The original forest cover for most of American Samoa was dense tropical rain forest. However, nearly two-thirds of the rain forest has been destroyed or damaged by man's activities, leaving undisturbed forests only on steep slopes. Plantations (primarily taro and coconut) are the most extensive land use, covering 34 percent of the land. Secondary forest covers 20 percent and includes all of those successional vegetation stages present after agricultural land has been abandoned. The only types of vegetation left relatively undisturbed are cloud forest, montane scrub, and littoral (coastal) vegetation. Unlike elsewhere in the Pacific, disturbed vegetation and secondary forest in American Samoa are not dominated by exotic plants (4).

Table 23.—Land Use in American Samoa, 1977

Land use	Acres
Developed land	7,830
Residential	2,475
Subsistence agriculture	1,620
American Samoa Government	1,087
Other	2,648
Undeveloped land	40,930
Total land area	48,760

SOURCE: American Samoa Government, *Economic Development Plan for American Samoa, FY 1979-1984* (Pago Pago: Development Planning Office, 1979).

Trust Territory of the Pacific Islands

The Trust Territory of the Pacific Islands (TTPI) includes roughly two-thirds of Micronesia: the Caroline and Marshall archipelagoes. TTPI includes high volcanic islands of varying ages, elevated platforms of coral limestone, and low flat coral islets and atolls (table 24). Coral atolls are characterized by the coconut palm and its related plant associates—breadfruit, pandanus, and shore plants. The high volcanic islands usually have mangrove swamps on the tidal flats, coconut vegetation inland and on the slopes, and mixed forest growth on the uplands (fig. 23).

Photo credit: C. Hodges

Subsistence agriculture, a major land use in the western Pacific, is one cause of American Samoa's forest loss

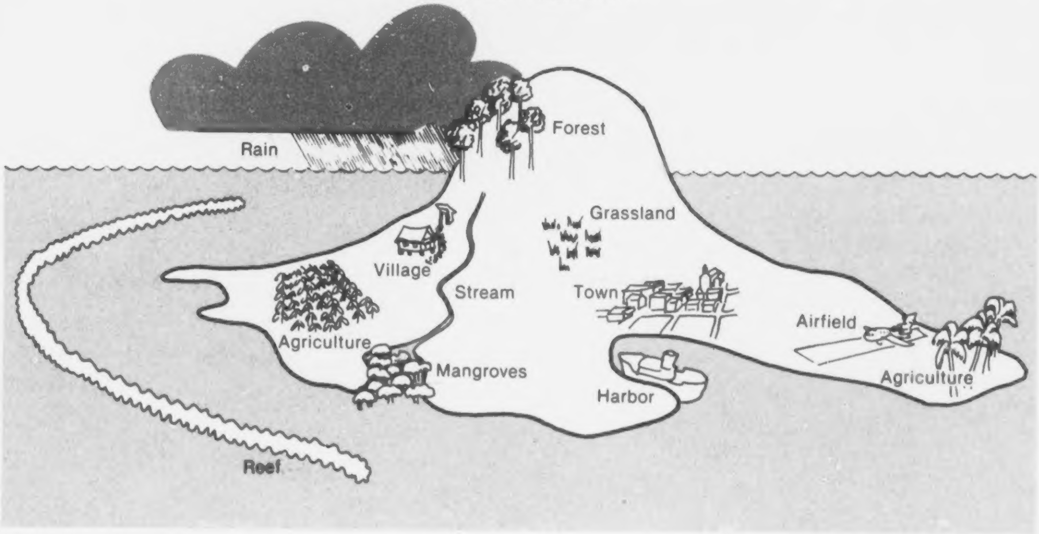
Table 24.—Island Types and Forest Areas of Micronesia (acres)

District	Dominant type of island	Mangrove forest	Savanna	Other forest
Federated States of Micronesia:				
Ponape[a]	High volcanic	13,690	3,567	67,614
Kosrae[a]	High volcanic	4,030	38	22,723
Truk	Volcanic peak	3,315	89	133
Yap[a]	Low volcanic	906	4,989	8,040
Republic of the Marshall Islands	Low coral atolls	10	n.a.	640
Republic of Palau:				
Northern islands	Low volcanic	9,344	19,560	18,816
Southern islands	Limestone			

[a] Forest area figures from C. D. Whitesell, personal communication, 1983.

SOURCE: Compiled from Burton R. Emmons, "Forestry in Micronesia" (unpublished paper, located at Library of the Office of Territorial Affairs, Department of the Interior), 1971; and U.S. Department of State, *Trust Territory of the Pacific Islands, 1980*. Report to the United Nations on the Administration of the Trust Territory of the Pacific Islands, Washington, D.C., 1981.

Figure 23.—Diagram of a "Typical" Micronesian Island Indicating Some Relationships Between Land Development and Island Resources



SOURCE: N. H. Cheatham, "Land Development: Its Environmental Impact on Micronesia," *Micronesian Reporter*, Third Quarter 1975, pp. 8-10.

Soil fertility is sufficient for the subsistence farming that is practiced—coconut culture and manmade taro pits on coral islands, and taro swamps, agroforestry, and garden culture on the volcanic and limestone islands. Where production is intensified, fertilizers must be used to sustain continuous production.

Leaching of plant nutrients is considered a more severe land-use problem than erosion. The combined loss of soil fertility from leaching and crop harvest has so depleted the available plant nutrients that certain areas in the high islands no longer can support sufficient vegetation either to protect against erosion or to provide enough nitrogen and organic material for crop growth (35).

Commonwealth of the Northern Mariana Islands

The Commonwealth of the Northern Mariana Islands comprises 14 islands of the Marianas archipelago, excluding Guam. The archipelago can be divided into a group of young, mostly active volcanoes and a group of older islands of elevated limestone and old, weathered volcanic rocks. The Northern Marianas have a land area of 76,000 acres. The largest islands of Saipan, Rota, and Tinian (covering 30,000 acres; 25,000 acres; and 21,000 acres respectively) are high limestone/volcanic combinations.

The steep ash slopes of the volcanoes are generally covered by a dense, coarse grass *(Miscanthus)*. Mixed forest and coconut plantations cover the flatter areas near the sea. Volcanic areas can be quickly colonized by exotic nitrogen-fixing *Casuarina* and other trees, but the common practice of burning maintains these areas in grasslands (4). The limestone regions of the older islands are predominantly covered with dense secondary forest. Some sugar cane is grown where the soil is deep enough.

Man has influenced the vegetation of the Marianas for at least 3,500 years. On old volcanic soils, accelerated clearing and burning in recent centuries have created a secondary forest in some areas and much secondary savanna. Erosion and soil deterioration have accompanied the process, making natural regeneration of the savanna a slow process. On fertile limestone soils, the forest has been replaced by coconut plantations, pastures, open fields and gardens, or secondary forest.

Guam

Guam is the largest and southernmost island of the Marianas chain, covering 135,000 acres. The northern half of the island is mostly flat or gently sloping limestone with a thin lateritic soil. In contrast, the southern half is composed of ancient, deeply weathered volcanic material. Except for a coastal plain on the western side, this southern area has a generally rugged terrain with a thick, acidic clay soil that contains little humus. More fertile soils occur on the coastal plains and valley mouths.

Once forest covered the entire island, but human disturbances and frequent typhoons, together with military activities during and after World War II, has left little undisturbed forest on Guam. Only scattered patches remain in inaccessible areas. Southern savannas are believed to be mostly the result of repeated burning. In this region, forests are scattered in ravines, valley bottoms, and steep slopes.

In Guam, towns, villages, and military reservations occupy under 10 percent of the land, although the U.S. military controls roughly one-third of the island (25). About two-thirds of Guam is in public ownership, both Federal and territorial (table 25). Private landholdings are largely in the southeastern and central parts

Table 25.—Landownership in Guam

Landownership	Acres
Private ownership	55,000
Public ownership	80,000
U.S. military and other holdings	52,000
Territorial Government of Guam	28,000
Total land area	135,000

SOURCE: C. D. Whitesell, C. W. Philpot, and M. C. V. Falanruw, "Congressional Action to Improve the Sustainability of U.S. Tropical Forest Resources in the Pacific," OTA commissioned paper, 1982.

Photo credit: B. C. Stone for NAS

Although once completely forest-covered, 50,000 acres of open or grass-covered land on Guam are barren and actively eroding of the island. They are mostly in small parcels and titles are often uncertain.

Little land on Guam is used intensively. No more than 2 percent of the land is actively cultivated (46). About 70,000 unmanaged acres (52 percent) have a cover of brush or trees including some 10,000 acres of abandoned coconut groves. About 50,000 acres (37 percent) of open or grass-covered land exist, little of which is grazed. In the southern part of the island, some of the open land is barren and actively eroding. Significant portions of both wooded and grass-covered lands are under military control, which restricts or prevents other uses.

In general, Guam's forests typify those of Micronesia; they remain unmanaged and their productivity is relatively low. Local populations seem little concerned with productive land use as imports provide more desirable substitutes (46). Growing populations are gradually generating pressures that will lead to conversion of the native forest to agriculture and urban areas. Eventually, however, agricultural lands will be largely depleted of nutrients and will be abandoned. These lands, and those already converted to nonproductive wasteland or scrub forest, may be designated "forest land," but foresters can only make such lands productive with great ingenuity, patience, and substantial investments.

History of Forest Use

Pre-U.S. Administration

The original inhabitants of Micronesia made few modifications of their environment. Traditional agriculture activities caused only minimal soil erosion. Low areas just inland of the coastal mangrove forests have been used for taro patches, changing the mangrove's species composition but retaining their capacity to filter and retain sediment.

Traditional agroforestry practices still found on the islands of Truk, Yap, and Ponape produce food while maintaining a cover of trees to protect and stabilize the soil. Coconut and breadfruit are interplanted on Truk's steep lower slopes. On Ponape, yams are planted below trees which they climb. The tree drops some or all of its leaves as the yam grows, providing green manure. Many species of food trees grow on Yap, and their harvest is alternated with produce from taro patches and yam gardens. Burning is used to open up small garden areas and to produce ash fertilizer under trees and bamboo patches (13).

Forests began a gradual decline following the arrival of the Spanish on Guam some 300 years ago. As the Spanish, and later the Germans, gained control, many islands—especially atolls—were eventually cleared, primarily for coconut plantations. The Germans also introduced teak, kapok, and a few other forest tree species during their administration from 1887 to 1914.

In 1914, the Japanese occupied nearly all of Micronesia except Guam and a few small islands. Within a few years, the Japanese had cleared all lands considered suitable for agriculture, and new crops such as pineapple and sugar cane were introduced. Copra production was increased, forests were cut for lumber and charcoal, and thousands of laborers, tradesmen, and their families came from Japan and Okinawa. Refineries, packing plants, large towns, and fortifications were built. Agriculture and forest experiment stations were established and research was conducted, including studies on nitrogen-fixing legumes and forest tree species introductions.

Most of these developments were destroyed during World War II. Commercial agriculture ceased and most fields were abandoned. Now they are covered with brush, grass, or trees, and are degraded from erosion and fires. By the middle of this century, most of the forests of Micronesia had been at some time either destroyed, cut, or converted to agriculture. Many forests are recovering and trees are approaching merchantable size. However, these frequently are species of limited use and commercial value. Remaining native forests and some secondary forests in Palau, Ponape, and Kosrae contain useful native species.

Centuries of colonial rule and great distances between Micronesian islands have resulted in many different forms of landownership. Much landownership is communal, and in some places items such as buildings or individual trees may be owned separately from the land. Land transfer and management authority may be vested in a family member, a village officer, or a village group. Individual ownership is relatively new. This leads to landownership disputes that have major impacts on the status of forest lands, especially the mangroves.

U.S. Administration

Administration of forest resources in Micronesia has been conducted by the U.S. Navy, Department of the Interior, Territory Governments, and now the emerging semi-independent governments. During the 37 years of American control, the forest resource "managers" at various times have been American foresters, agriculturists, biologists, conservationists, military planners, and local island foresters. Some have initiated, while others have ignored, forest management practices and forestry-related research. Political changes and frequent personnel turnover have eventually negated much of the constructive work started over the years in Micronesia. Other factors also have played important roles in determining the present condition of the forest lands, including World War II destruction, fires, typhoons, vandalism, timber theft, neglect, noxious weeds, impoverished soils, and inadequate funding of conservation programs.

One of the more successful U.S.-supported efforts in Micronesia has been the work of agriculturists. Specialists have come and gone over the years, but a dedicated core accomplished some important work with limited budgets, staff, and facilities. Technologies such as those available through the U.S. Agency for International Development programs to lesser developed countries were seldom funded to any significant extent in Micronesia. Consequently, little is known about such things as soil nutrient deficiencies and crop nutrient requirements under the islands' conditions (46).

Fire is the biggest technical problem to overcome in rehabilitating grass lands. Each year, fires are started and allowed to burn uncontrolled. They sweep through the grasses to the edge of the forest, destroying forest along the margin. This deforestation is disrupting island hydrology. For example, older inhabitants of Northern Babeldaob (Palau) remember when the streams ran all year long. Now, due to repeated burnings, the forest cover has been destroyed and the streams run only when it rains, and then they are often fast and muddy (11).

In the 1960's, the TTPI agriculturists brought thousands of improved varieties of coconuts from Yap to the Marshalls and other islands. However, this rehabilitation project was not completed. Local economies now suffer and two new processing plants, one in the Marshalls and one in Palau, have had low production and low profits because of a copra shortage. In fact, it has been necessary to import copra from Papua New Guinea to keep the Palau plant operating.

The condition of coconut plantations on many islands is of serious concern. Many were planted by the Germans around the turn of the century and they are now senescent. For many inhabitants of the U.S. Pacific, coconut growing is the only nongovernment source of cash income. Despite its importance, the copra industry in Micronesia and American Samoa is in trouble on three fronts: 1) the world price is low (in competition with other copra producing areas and other vegetable oils); 2) yields are low and most of the plantings are old, well beyond the productive life of the palm; and 3) while copra is not the only product derived from the coconut, the other major potential product—coir fiber—is wasted (34).

Organizations Dealing With Tropical Forests

Forestry programs in the U.S. Pacific consist primarily of localized extension efforts and limited nursery activities. Industrial forest use is limited to harvesting small commercial

Photo credit: C. Whitesell

Fires set to clear land for planting crops, attract deer, and reveal brass left from World War II, destroy much forest each year

mangrove forests on Ponape and Kosrae. Individual trees are used by the crafts industry on most islands. The forests also provide some home construction materials on many islands. Forest use is being included in the economic development plans by the new governments.

The only forest research activities in the U.S. Pacific since the 1930's have been those conducted during the past 15 years by the American Pacific Islands Forestry Research Work Unit of the U.S. Forest Service. This Unit is one of three research teams that make up the Institute of Pacific Islands Forestry (IPIF) located in Hawaii. The Institute, in turn, is part of the Pacific Southwest Forest and Range Experiment Station. The Pacific Islands Forestry Research Work Unit is responsible for conducting cooperative research and information exchange with the U.S. Pacific Islands. Support is provided by the Forest Service Northwest Forest Experiment Station and the Hawaii Division of Forestry and Wildlife. The State and Private Forestry branch of the Forest Service provides technical assistance and cooperative funds to the forestry programs in the western Pacific.

The Forestry and Soil Resources Division of the Department of Agriculture in Guam has three professional foresters and two technicians. The land grant University of Guam has designated an experimental forest area, but no school in the U.S. Pacific has a forestry or integrated natural resource management curriculum. Ponape State passed a Forest Management Act in 1978 that provided for the protection and management of its forest and watershed areas. No forestry program exists in American Samoa. In 1983, the Commonwealth of the Northern Mariana Islands initiated a forestry program (47). Each emerging island government, with the exception of Palau, has a research memorandum of understanding with the IPIF and includes forestry in proposed development plans.

The forestry agencies responsible for forest protection and management in the U.S. western Pacific are either small or nominal. The extant and emerging governments have expressed an intent to include forestry in development and have designated forest agencies, but they lack funding and adequate professional personnel. Also, IPIF is attempting to address the forest research problems on 2,000 islands with only three professional staff and annual funding for only 2 scientist-years (table 26).

Table 26.—Organizations Dealing With Tropical Forest Resources in the American Western Pacific

Agency/Responsibilities

Federal Government:

- *Forest Service:* Conducts research and cooperative resource inventories; provides State, Territorial, and private landownership support, and manages Pacific Islands Forestry Information Center.
- *Soil Conservation Service:* Advises landowners about landuse alternatives including forestry practices; conducts cooperative soil surveys.
- *Fish and Wildlife Service:* Administers Rose Atoll Wildlife Refuge, American Samoa; conducts cooperative terrestrial inventories.
- *National Park Service:* Administers the National Historic Park in Guam.
- *Department of Defense:* Maintains a chief conservation officer on Guam overseeing DOD activities in the Pacific; maintains Patti Point Natural Area.
- *Peace Corps:* Sponsors volunteers to aid village development, forestry, etc.
- *Pacific Basin Development Council:* Partnership among U.S. Federal Government, American Samoa, Guam, Northern Mariana Islands, and State of Hawaii to determine the future development needs and priorities of the American Pacific Islands.

Island Governments:

These territorial agencies conduct programs in agriculture, forestry, fire prevention, fish and wildlife management, and outdoor reaction. Two forestry stations test nursery techniques and methods of rehabilitating and reforesting degraded grasslands and woodlands.

- *Territory of American Samoa:* Department of Agriculture
- *Territory of Guam:* Department of Agriculture, Bureau of Planning
- *Commonwealth of Northern Mariana Islands:* Department of Natural Resources
- *Republic of the Marshall Islands:* Department of Resources and Development
- *Republic of Palau:* Deparment of Natural Resources, Nekken Forestry Experiment Station
- *Federated States of Micronesia:* Kosrae State, Department of Resources and Development; Ponape State, Department of Conservation, Metalinin Forestry Experiment Station; Truk State, Department of Resources and Development; Yap State, Department of Resources and Development

Universities and colleges:

- *American Samoa Community College:* Designated a land grant college in 1983.
- *College of Micronesia:* Designated a land grant college in 1983.
- *University of Guam:* Land grant college.

Other:

- *South Pacific Commission:* Provides technical assistance, training, and some monetary assistance for agroforestry and ecology.
- *Yap Institute of Natural Science:* Identifies flora and fauna of western Pacific islands and traditional uses of medicinal plants on Yap.

SOURCE: Adapted from C. D. Whitesell, C. W. Philpot, and M. C. V. Falanruw, "Congressional Action to Improve the Sustainability of U.S. Tropical Forest Resources in the Pacific," OTA commissioned paper, 1982.

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PART II

Technology Assessment

Chapter 7

Technologies for Undisturbed Forests

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Chapter 7

Technologies for Undisturbed Forests

HIGHLIGHTS

Maintaining Sample Ecosystems

- Preserving samples of undisturbed tropical forests can help protect representative flora, fauna, and habitats and thus maintain biological diversity and goods and services provided by forests. But there is a disparity in the distribution of protected areas.
- It is essential to improve the management of existing protected areas, since many are protected only on paper. The United States can contribute by providing increased opportunities to educate and train resource managers and technicians.
- There is growing recognition that protected area management should include more socioeconomic and institutional considerations. The UNESCO Man and the Biosphere Program system of biosphere reserves is one approach that emphasizes these components. It, however, suffers from the lack of strong, consistent U.S. commitment and support.

Making Undisturbed Forests More Valuable

- The value of tropical forests could be increased by developing new products or by encouraging the collection and processing of existing products. This could be done with investment to analyze traditional uses of forest products, develop markets, and promote sustainable management systems.
- Improved assessment of the value of nonwood tropical forest products, especially in subsistence economies, could provide incentive to include development of these resources in economic development planning.

INTRODUCTION

Proven methods and techniques to sustain undisturbed tropical forests* are few. Of these, establishing parks and protected areas probably is the most common method. A few other examples exist where selected renewable resources are extracted from a tropical forest to generate income while the forest and its resources remain essentially intact.

Political expediency often determines when and where a park or protected area is established. The rapid loss of forests in most tropical countries forces people to try to establish protected areas whenever and wherever the opportunity arises regardless of whether adequate, continuing protection will be available to care for the land and its resources. Many protected areas exist only on paper and in fact continue to undergo destruction.

Resource conserving technologies that tap the potential of undisturbed forests, such as butterfly and crocodile farming (see p. 172), are rare. While these two examples affect few people, they are important illustrations of how human well-being can be linked directly to maintaining the productivity of tropical forest resources. Such systems can work, but a great need exists to develop other integrating approaches if such methods are to provide significant benefits while sustaining undisturbed tropical forests.

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*Undisturbed tropical forests are defined as areas where trees are the dominant woody vegetation covering more than 10 percent of the ground and where trees have not been cut during the past 60 years. This definition includes both primary and old secondary forest, both closed and open forest (22).

MAINTAINING SAMPLE ECOSYSTEMS

Why Protect Tropical Forests?

Parks and protected areas can fulfill a variety of objectives. These vary according to the character of the area, but can include:

1. protecting and maintaining representative samples of major biogeographical provinces to support evolutionary continuity and the health of the Earth's life support system;
2. protecting representative, as well as unique, samples of natural systems, landscapes, and life forms;
3. protecting natural areas needed to support development activities (e.g., watersheds and ground water recharge areas);
4. providing in situ* protection of plants and animals that may make substantial, though perhaps currently unforeseen, contributions to human development (e.g., supply new food or drug sources);
5. providing sites for research and education to increase scientific knowledge that can be used to develop new technologies to manage such systems;
6. protecting cultural, archeological, or natural monuments; landscapes of historical or cultural interest; or unusual geological formations; and
7. providing esthetic pleasure, opportunities for healthy and constructive recreation, and revenues from tourism (11).

Status of Protected Areas

Establishment of parks and protected areas in the world has burgeoned in the last two decades. The greatest increase in the number of protected areas has occurred in developing countries. Nearly one-half (160 million hectares (ha)) of the worldwide total of protected natural areas are found in the Tropics (3,21). Protected areas in Central America, for example, grew rapidly from 24 units (1.7 million ha) in 1969 to 124 units (4.8 million ha) in 1981 (2). Unfortunately, some of the designated areas are protected only on paper. No data are available on what portion of the parks and protected areas worldwide suffer illegal hunting, logging, farming, and livestock grazing, but anecdotal evidence suggests that such illegal use is a common problem in the tropical nations.

Substantial increases in the area given protected status over the past two decades indicate that the values of undisturbed forest resources are being more widely recognized. This progress is due at least in part to a growing awareness among nations of the social, economic, and ecological benefits accruing from appropriately managed protected areas (7,8).

An FAO/UNEP study indicates about 3 percent of the closed tropical forest has been given park or other legal protected status (see app. table A-2). Such protected lands are unequally distributed; at least half are located in just four countries—India, Zaire, Indonesia, and Brazil. In addition, the International Union for the Conservation of Nature and Natural Resources (IUCN), which monitors the worldwide distribution of protected areas, reported in 1981 that some ecological types are either not represented or are underrepresented by existing protected areas.

Techniques to Design, Establish, and Maintain Protected Areas

Siting Protected Tropical Forests

Many of the first tropical parks and reserves were established for esthetic and recreational purposes (14). Lands were set aside because of spectacular scenery or unique land forms, following the precedent set by the United States. Although such lands can provide income from tourism and recreation, they may not be designed or located to sustain other important values associated with undisturbed forests. Park borders in the past usually ignored animal migration routes and important adjacent ecosystems. Some areas in Africa, for example, protect important watering areas for wildlife

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*Protecting stock in the original habitat rather than in places such as gene banks or botanical or zoological gardens.

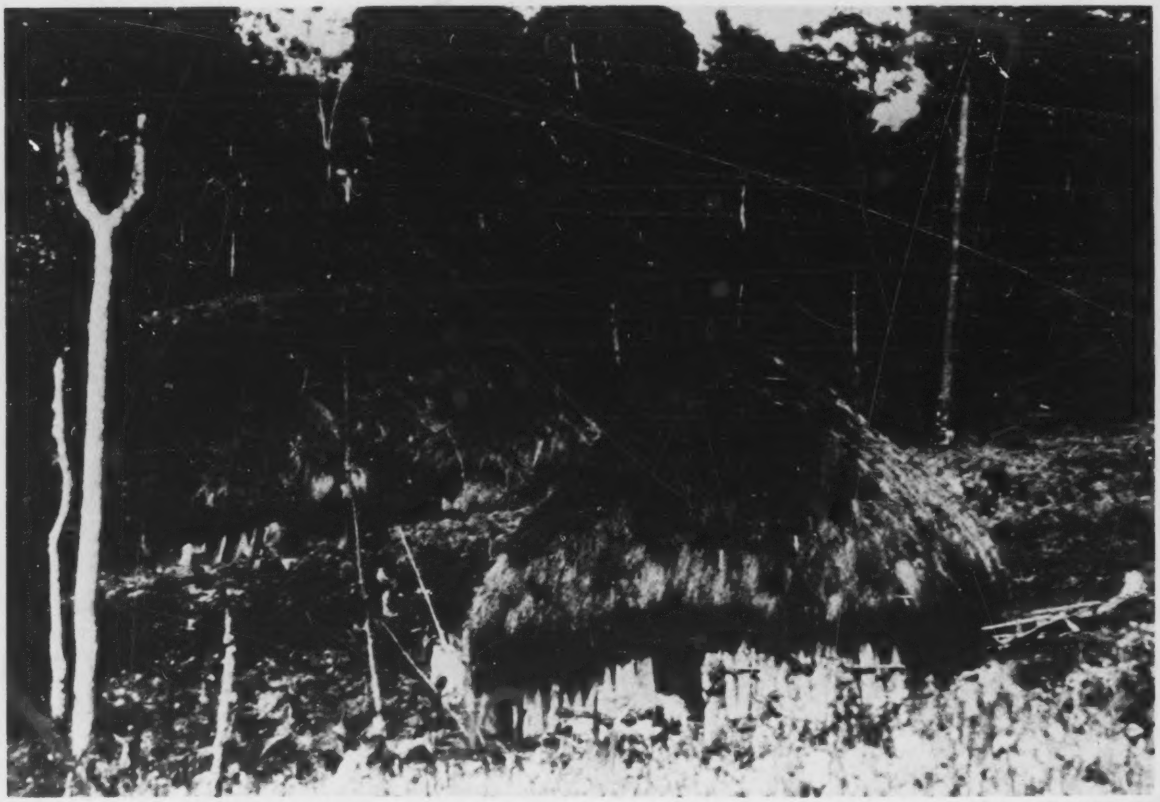


Photo credit: H. Bollinger

Forest clearing for agricultural settlement often proceeds in spite of the site's legal status as a protected area. This settlement is in a Kenyan forest listed officially as a preserve by the Forest Department

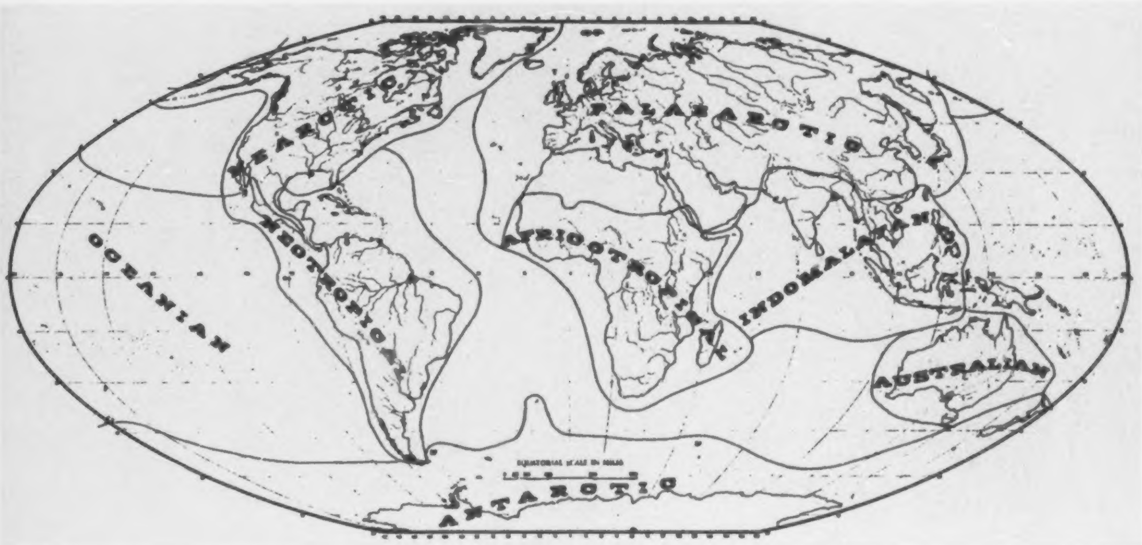
but do not protect the upland watersheds that are necessary to maintain water supplies. Furthermore, rural people living in or near parks have often been disregarded or displaced.

More recently, planners have begun to look beyond simple scenic values to emphasize a broad range of biological resources and environmental services in protected area designation. Techniques for siting areas to be protected are becoming more scientific and integrative.

A classification system used to identify appropriate locations for protected area establishment worldwide is based on ecological categories. This system divides the Earth into eight large "realms" (fig. 24), which in turn are subdivided into 193 biogeographical "provinces" (21). Realms are continent or subcontinent-sized areas with unifying features of geography, fauna, and vegetation. Provinces are more detailed subdivisions, each characterized by a major biome type such as "tropical humid forest," "tropical grasslands," or "tundra communities." Ideally, selection of protected sites should include representative samples from each realm and province.

Within a province, the location—as well as the number, size, and shape of protected areas—is important to biological conservation. The scientific basis for determining these characteristics is theoretical. Few studies have tested the theories with species other than birds (18). Two criteria have emerged for selecting sites to safeguard biological diversity. One is

Figure 24.—Terrestrial Biogeographic Realms of the World



SOURCE: M. Udvardy, *World Biogeographical Provinces*, IUCN Occasional Paper No. 18, 1975.

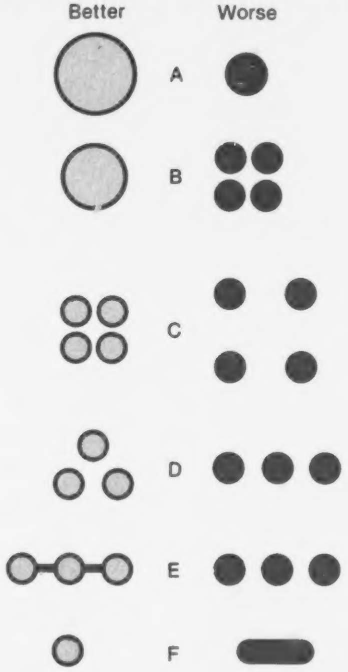
the relative degree of species **endemism** of a particular site. Areas of high species endemism are those containing many highly localized species. A related criterion is the number of species, or **species diversity**, at the site. All else being equal, the more biologically diverse a site, the greater its potential value.

A number of inferences about how park size and shape affect maintenance of biological diversity have been drawn from studies of tropical island biogeography (fig. 25). These studies have found that the risk of species extinctions within a protected area—in essence a biological island—can be minimized through careful design of the site. An appropriate size can be determined by including all the natural features that constitute a self-sustaining ecological system. However, to maintain their full complement of plant and animal species, most sites need to be large. This is because many tropical species occur naturally at low densities. Below a certain minimum population, these species are more vulnerable to problems of population instability and the risk of extinction.

For example, the minimum viable population size for long-lived organisms with low natural mortality rates is believed to be about 50 individuals in the short term (50 to 100 years) and 500 in the long term (6). Ideally, sites should contain at least this number of their rarest species. The size required to do this varies with type of species and ecosystem, but determining actual size is an area of great scientific uncertainty. Recently, scientists in Brazil have begun a series of experiments to measure rates of loss of biological diversity that occur with variations in protected area size and shape under various tropical forest conditions (12). Such research produces results slowly. In the meantime, some scientists have suggested 2,500 square kilometers as the minimum area of tropical rainforest needed to safeguard most species (20). This suggested rule-of-thumb often is impractical, given the socioeconomic and political situations of many tropical countries.

Biogeographical considerations are only some of the factors needed to determine the appropriate shape of protected areas. Where

Figure 25.—Design of Protected Areas



Suggested geometric principles, derived from island biogeographic studies, for the design of protected areas. In each of the six cases labeled A to F, species extinction rates will be lower for the reserve design on the left than for the reserve design on the right.

SOURCE: International Union for the Conservation of Nature, *The World Conservation Strategy* (Gland, Switzerland: IUCN/UNEP/WWF, 1980).

maintenance of specific environmental services is a high priority, it should be reflected in the area's shape. For example, watershed catchments have specific shapes. In addition, the needs and interests of local people also should help determine the shape, size, and location of protected areas.

Establishment and Management Techniques

Different categories of protected areas such as national parks, biological reserves, and cultural monuments serve different objectives and purposes. The management strategy chosen depends on the particular combination of benefits that are desired (table 27). Protected areas should include two types of reserves: 1) lands where ecosystems are protected with a minimum of human manipulation (sometimes called strict nature reserves or national parks); and 2) lands where particular resources or parts of the ecosystem are protected, but where collection of some products and some manipulative research is allowed and managed, particularly for education and training (11).

Table 27.—Wildland Management Categories

Management category/Characteristics

1. ***National Park:*** Wild or primary ecosystems with little evidence of human intervention; contains unique features of national or international significance.
2. ***Natural monument:*** An area generally encompassing only one natural feature that is of national or international significance.
3. ***Scientific or biological reserve:*** Lands that are generally not altered by man and contain floral and/or faunal species of national or international importance. Size depends on habitat needs of target species.
4. ***Wildlife sanctuary or refuge:*** Land encompassing the vital habitat resources of animal species or communities of national or international significance.
5. ***Resource reserves:*** A transitory state where a primary ecosystem will be maintained in a natural state until more definite management goals are determined.
6. ***National forest:*** Extensive forested lands important for wood production and watershed protection.
7. ***Game reserves:*** Lands containing populations of native wild species of fauna and/or habitat suitable for the production of wild fauna protein, animal products, or for viewing or sport hunting.
8. ***Protection zones:*** Generally small areas that do not meet the objectives of other wildland categories but that require the kinds of strict land-use control provided by wildland management techniques.
9. ***Recreation areas, scenic rivers, and highways:*** Relatively large areas with outstanding natural or seminatural scenery and the physical potential to be developed for a variety of outdoor recreational uses.
10. ***Scenic easements and rights-of-way:*** Regions outside of park or reserve boundaries that merit protection, usually for esthetic reasons—i.e., access roads, shorelines, mountains, scenic overviews, etc.
11. ***Cultural monuments:*** Sites or areas containing historical, archeological, or other cultural features of national or international significance.
12. ***Integrated river basin or regional development programs:*** Integrated regional land-use planning that includes wildlands conservation as an integral component of development.

SOURCE: K. Miller and D. Glick, "Methods for the Establishment and Management of Protected Areas for Tropical Primary Forest and Woodland Resources," OTA commissioned paper, 1982.

Simply designating protected areas on a map does not assure that the land will be managed to provide the greatest possible benefits. A management plan is needed. A planning procedure that has proven effective for a variety of tropical wildland conditions is shown in table 28. This process is continuous and interactive with built-in monitoring and evaluation components. Thus, the procedure helps ensure that data on how management affects the resources within the designated site, how it affects the surrounding area, and how the surrounding area affects the site will be collected and continually used to improve management.

The traditional approach to park establishment and management has often failed to take into account local cultures and has excluded local people. Consequently, protection of designated areas has often not been effective. Local people, with no incentive to protect the park, ignore the area's legal status. Given increasing needs to develop rural lands in recent years, protected area planning has begun to incorporate more economic and social consideration (14). Although some socioeconomic and other social science analyses are being incorporated into the planning process, methods to use these data as yet are not fully used.

Appropriate management of tropical forest protected areas necessitates active participation by many individuals and groups. The principal participants include:

1. *Planning Team.*—Establishment and management planning is best conducted by a team of specialists representing both environmental and sociological fields (e.g., park planners, ecologists, foresters, wildlife biologists, rural developers, anthropologists, sociologists, economists, environmental educators, and community developers).
2. *Rural People.*—The people living in or adjacent to proposed or established protected areas must play an active role in park planning, establishment, and management. Meeting their resource needs is an important factor in the success of a protected area.
3. *National Decisionmakers.*—Government and nongovernment leaders must support conservation activities if adequate financial and legislative support for forest protection is to be procured.
4. *The General Public.*—If widespread public support exists for the creation of parks and reserves, government leaders are more likely to support such efforts.
5. *The Global Community.*—International political and development agencies can be instrumental in promoting wildland protection. Development of tropical forests in many cases is directly affected by multinational businesses and global political bodies (14).

This broad approach, although it can be unwieldy, facilitates involvement by both those people who directly or indirectly will affect or be affected by the forest resource (generally rural people) and the people and agencies that must support or implement the management programs.

Support from local citizens can be increased if protected areas are designed so benefits accrue to local inhabitants (25). An example is Nepal's Royal Chitwan National Park. Chitwan was declared a park in 1973 to demonstrate that the conservation of nature was an integral part of Nepal's plans for economic develop-

Table 28.—Steps in Planning a Park or Protected Area

1. Gather basic background information, including analysis of administrative, organizational, legal, and political context for the park.
2. Conduct a field inventory of natural and cultural resources and land-use and development aspects of the area.
3. Analyze constraints on planning the park.
4. State specific objectives on planning the park.
5. Divide the area into management zones, identifying sites where specific activities and developments are to take place.
6. Draft preliminary, practical park boundaries.
7. Design management programs for protecting, using, and administering the park.
8. Prepare an integrated development program for the plan: what is to be built; what supplies, equipment, and materials are needed; what infrastructure and utilities are required; and what staff and institutions will be involved.
9. Analyze and evaluate the proposal.
10. Design the development schedule.
11. Publish and distribute the management plan.
12. Implement the plan.
13. Analyze and evaluate the plan.
14. Solicit feedback and revise the plan as needed.

SOURCE: K. Miller and D. Glick, "Methods for the Establishment and Management of Protected Areas for Tropical Primary Forest and Woodland Resources," OTA commissioned paper, 1982.

ment. The park's conservation record is impressive: its population of rhinoceroses rose from about 100 in 1968 to at least 300 in 1978, and its tiger population increased from 25 in 1974 to as many as 60 in 1980 (15). But that success created conflicts with local residents. They suffered loss of crops, livestock, and occasional loss of life caused by park animals and they encountered other conflicts with park regulations. But as part of a broad program of resettlement, public participation in the park's management, and compensation for losses, the government decided to allow villagers to use the park to collect tall grasses for building materials. Since most of the needed thatch grasses outside Chitwan had disappeared, the people realized that the park protected their interests, too, and relations have improved considerably (15).

It is also important to ensure that once areas have been designated, their status should not be changed except for some compelling higher public interest. Because of the need for coordination and top-level decisionmaking, the power to establish any protected area should be by law. Approval should be required of the highest body responsible for legislative matters in the country or region—e.g., parliament or legislative assembly. Similarly, amendment or abolishment of any protected area should be through superseding legislation and determination of this highest authority. This may not be politically or administratively possible in some countries. In cases where the highest legislative level of approval is not possible, review and approval should be required at least from a competent authority at a level higher than the agency which is responsible for managing the protected area (11).

Finally, even if all elements of appropriate tropical forest management are met, the destruction of adjacent ecosystems can seriously affect resources within the reserve boundaries. Therefore, protected areas management must broaden its scope of concern from protecting "patches" of natural areas to implementation of environmentally appropriate land-use practices in nonpark areas (18). The complementarity of conservation and development increasingly is appreciated as protected areas are incorporated into broader regional and local development plans and into development projects to enhance their economic performance.

The UNESCO-MAB Concept. Few innovative conservation actions have been developed to integrate protected areas directly with the surrounding biophysical and socioeconomic setting. One program with this objective is the United Nation's Man and the Biosphere (MAB) Program initiated by UNESCO in the early 1970's. The goals of MAB are to encourage the study of human impact on natural renewable resources and promote the application of appropriate knowledge and experience to maintain these resources for long-term development. The MAB program also provides a network for information exchange among developed and developing countries.

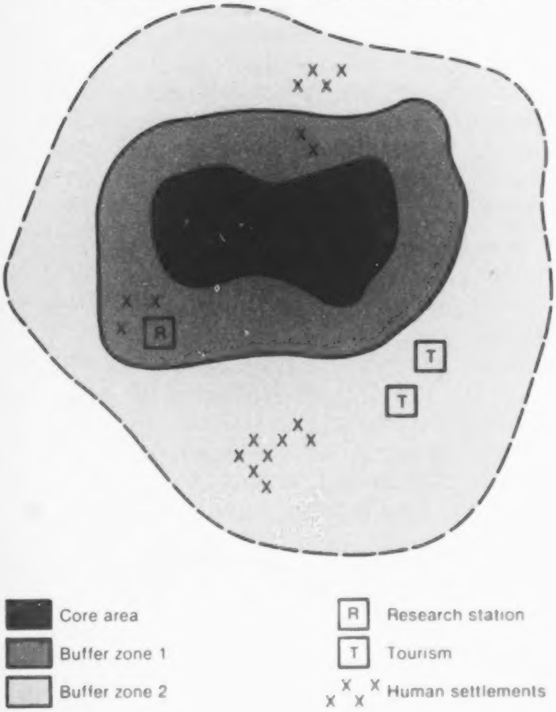
The MAB biosphere reserves program attempts to integrate conservation of protected areas with surrounding socioeconomic needs. The biosphere reserves use management and zoning to facilitate human activity within certain sections of the reserve (5). This concept emphasizes the needs of local populations and seeks to define ways where specific economic benefit in the form of revenues and products from the reserve can be returned to the local people.

Biosphere reserves are intended to be a worldwide network of protected land and coast environments linked by international understanding of purposes and standards and by exchange of scientific information. Ideally, the network should include significant examples of all the world's biomes. Each biosphere reserve also should be large enough to be an effective conservation unit and to accommodate different uses without conflict.

The zoning concept applied to a biosphere reserve normally includes a well-protected "core area" surrounded by one or several "buffer areas" where manipulative research or ecologically sound land uses are allowed. This buffer acts as a transition zone integrating the reserve into the surrounding region. The design of a reserve (fig. 26) can be adapted to different geographical, ecological, or cultural situations, including, for instance, cases where animals migrate from one part of the reserve to another or where a cluster of core areas need protection. This concept differs from traditional designs because it is an open, rather than closed, system. It considers the management problems of the surrounding areas and provides for needs of local populations (1).

Each participating country designs its own program under the minimum requirements of MAB. Thus, practices vary from country to country depending on available manpower, resources, and political commitment. Representation to MAB, however, may provide a tool for developing-country experts to improve the national and international visibility of their conservation work. To a limited extent, the UNESCO-MAB program can sponsor outside experts to provide technical assistance in countries where they are needed.

Figure 26.—A Typical Biosphere Reserve



In the comparatively short life of the MAB biosphere reserve effort, the concept behind biosphere reserves—the improved integration of long-term conservation and socioeconomic needs—has become increasingly recognized as an important and, in some areas, a critical tool for effective conservation of natural systems. However, additional field experience and monitoring are needed to evaluate the successes of existing biosphere reserves. Current indications seem to be that biosphere reserves suffer from some of the same problems as other protected areas—lack of adequate institutional support, lack of adequate staff and funds, and poor coordination with other activities and with government concerns.

Conclusion

Actions to establish and manage protected areas could help protect undisturbed forest resources and prevent some resource degradation in the Tropics. Protecting sample ecosystems in some system of protected areas can be an important technique to preserve representative flora, fauna, and habitat and, thus, maintain ecological diversity and a range of goods and environmental services in tropical areas.

An unknown number of the Tropics' protected areas are inadequately managed and suffer deforestation and other resource degradation. Factors that contribute to these problems are a lack of commitment at the government level, insufficient funds, and scarcity of trained personnel in tropical countries to carry out the many tasks involved in planning, designing, and managing protected undisturbed tropical forests. If the first two factors persist, it may be preferable to improve the management of existing protected areas through appropriate institution-building activities rather than create new areas on paper which would further overextend the limited funds and human resources. Since lack of appropriately trained personnel is an important constraint, the United States can make a significant contribution by making U.S. expertise more readily available—through universities, nongovernmental organizations, and government agencies such as the National Park Service.

The objectives of protected areas have evolved from strict protection to a broader approach that considers socioeconomic and institutional factors. Thus, the need to develop and test methods based on the latter approach grows. Few such conservation techniques have been developed. The MAB biosphere reserves are one attempt to integrate conservation with development. However, development of the biosphere reserve concept is still at the experimental stage in both tropical and temperate zone countries. The U.S.-MAB effort, while effective considering the minimal funding it has received, is constrained by a reduction of support and a lack of a strong, consistent U.S. Government commitment. Stabilizing the U.S. commitment to MAB would enable U.S. scientists to contribute their skills and expertise to develop further this innovative conservation option. This might encourage additional international support for various MAB programs as well.

MAKING UNDISTURBED FORESTS MORE VALUABLE

The environmental services provided by undisturbed forests frequently are not enough incentive for individuals to maintain uncut forests. One way to clarify the importance of uncut tropical forests is to document the value of their environmental services and use this information to convince government decisionmakers to invest in protecting the forests. However, while this is important for parks, it has not proven a practical method to protect large forest areas in less developed countries. Another approach is to enhance the value of forests by managing them for wood production. However, cutting trees is disruptive of the forests' ecology and, for many types of tropical forests, wood harvesting technologies that are profitable and yet do not degrade the resource base have not been demonstrated. Thus, both for legally protected areas and for certain other undisturbed areas, sustaining the forest depends on making it more valuable without cutting the trees.

Many useful and valuable forest products are produced with little or no associated wood harvest. More organized harvesting, processing, and marketing of these products, coupled with development of new products, markets, and management infrastructures (including organization of local institutions to regulate harvesting) could greatly enhance the value of undisturbed forest (17,23).

Nonwood Products

Nonwood products include those obtained from the wood, bark, leaves, or roots of trees as well as products obtained from other vegetation and from animal and insect life in the forest. These products obtained near and in forests are directly or indirectly dependent on forest ecosystems. Examples include gums, resins, drugs, dyes, essential oils, spices, naval stores (turpentine, rosin, and derived products), and livestock forage as well as a wide variety of fibers used to make baskets, mats, ropes, and buildings. The value of some of these products is not well quantified. Some, such as certain specialty oils, may be relatively unimportant economically. Others, such as natural-base pharmaceuticals and certain fibers used in household goods, serve currently irreplaceable functions, either locally or internationally.

One example illustrating the potential of nonwood tropical forest products is silk, a product gathered for thousands of years in some areas, yet having considerable potential for development. Most silk is produced by domestically reared caterpillar larvae on a strict mulberry leaf diet. In India, however, an extensive cottage industry produces silk from wild tasar silkworms that feed on a variety of wild trees. For centuries, forest-dwelling people have produced this coarse, strong, tan silk. Tasar silk

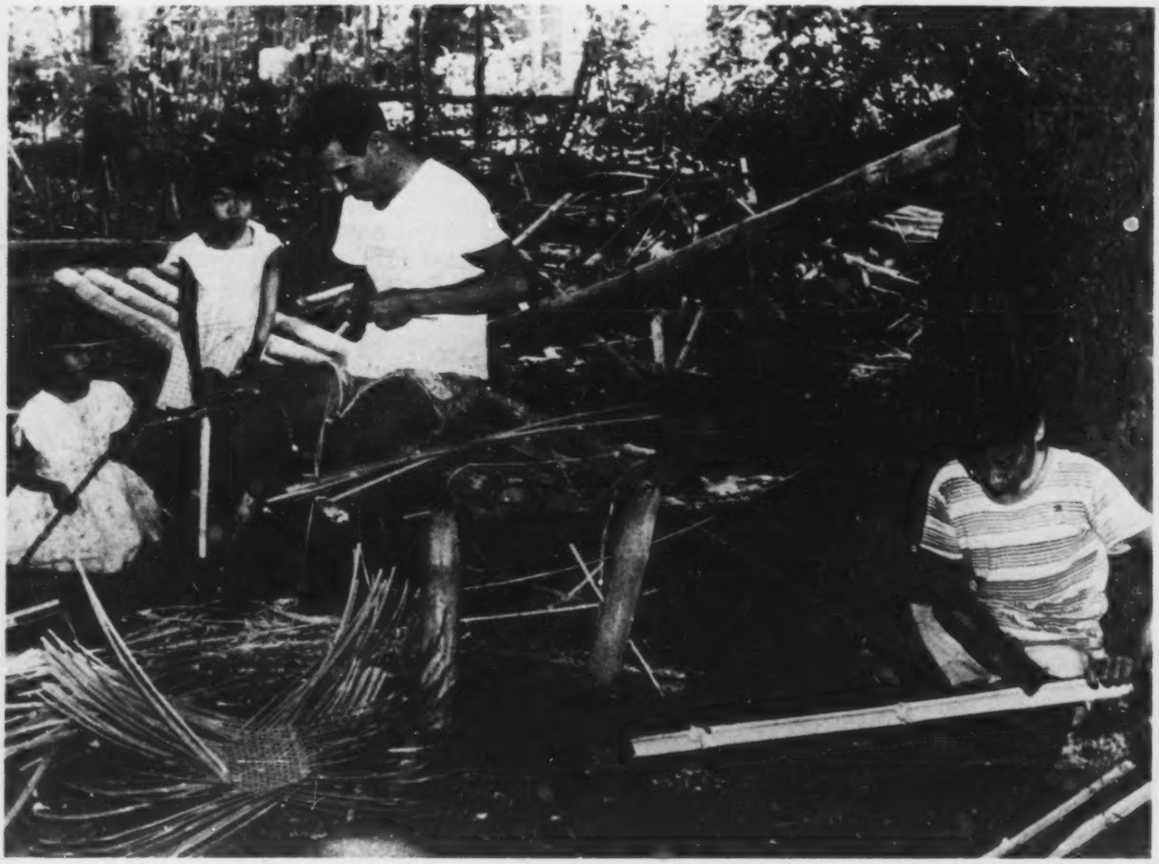


Photo credit: S. Bunnag for FAO

Bamboo has many subsistence and commercial uses, including village handicrafts. Here Philippine villagers make "birdcage" lampshades for the tourist market

export earnings in India totaled US $4.4 million in 1976 and the industry employed at least 100,000 families (9).

Tasar silk is secreted by several species of the genus *Antheraea*. India alone has at least eight species, but only one, *A. mylitta*, has been exploited commercially. The little research that has been done to improve production shows great promise: breeding experiments have produced a 169-percent increase in silk weight. Similarly, tests of rearing techniques have shown potential to increase the average income per family from $30 per year to $250 in 45 days (10).

The main tasar silk-producing countries today are China and India. However, the food plants that can support tasar silkworms cover 7.7 million ha in the Tropics. This seems to offer significant opportunity for other developing countries to develop industry, employment, income, and a raised standard of living for forest-dwelling people while encouraging maintenance of forest ecosystems that are habitat for the silk-producing species (9).

Forest Food Sources

Meat from wild animals and fish, fruits, nuts, honey, insects, fungi, and vegetables are all important forest food sources. Despite the impact of modern agricultural techniques and crops, in many parts of the world these wild food sources continue to contribute significantly to local diets. In regions that are unsuitable for conventional animal husbandry, "bush meat" is often a main source of animal protein. For example, in Ghana nearly three-quarters of the meat consumed is from wild animals (4). Even where cultivated crops such as cassava or corn are staples, the great variety of food types available from the forest is important for adequate nutrition.

Small Animals

Giant rats, turtles, capybara, grasscutters, and other small animals are sought-after foods in some developing countries. With scientific husbandry, these animals could become important sources of much-needed protein. Further, the development of some of these food sources could provide incentives to sustain tropical forests.

Capybara, for instance, are the world's largest rodents—they weigh up to 100 lbs. Capybara live in family groups on the edges of ponds, lakes, rivers, and swamps in Central and South America. They eat only plants—preferring coarse swamp grasses, aquatic plants, and weeds such as water hyacinth. Wild and semidomesticated capybara has been a meat source for centuries, but only recently have Venezuelans begun farming them. Researchers there report that capybara digest food 3½ times more efficiently than cattle. They are fecund, producing six young in a year. Further, their leather commands a high price and is sought by glovemakers because it stretches in one direction only (4,24).

Examples of Nonwood Products

Various **essential oils** are obtained from natural sources. For instance, sandalwood oil is one of the best known of all perfume oils. It is produced mainly in India from both wild and cultivated trees. Attempts to synthesize the oil have been unsuccessful.

Chemicals, including drugs, are important forest products for both local and world populations. Various modern pharmaceuticals—e.g., quinine from cinchona bark—are of tropical origin. Another useful forest chemical is lac used in shellac, waxes, and binding and stiffening agents. Lac is secreted by a tropical insect that feeds on tree sap.

Gums such as chicle are obtained from wild trees in forests of Central America. Natural gums are primary ingredients of chewing gum and are used in many processed foods. They contribute both to export revenue and to local employment.

Naval stores—turpentine, rosin, and derived products—can be produced from tropical pines by a technically simple process without damaging the trees.

Forage is another traditional benefit provided by forest resources. Ground and tree vegetation are both used—though tree fodder is particularly important in areas with a prolonged dry season. In the past, there has been little active management of forest fodder resources.

Fibers obtained from forest vegetation are especially important in subsistence cultures, where they are used for making baskets, mats, rope, furniture, and in construction. Some fibers are marketed (e.g., for wicker-work).

Spices are found in and around most forests, though commercial production is usually in plantations. Pepper, clove, nutmeg, cinnamon, and vanilla typically are plantation crops but do exist in the wild. Cardamom is harvested both in the wild and from plantations. The plant thrives in the shade and might increase the per-hectare return from tropical forests.

Examples of Forest Food Sources

One of many forest **fruits** is the multipurpose *Borassus* palm. The milk of the unripe fruit is marketed as a nourishing and popular drink. The ripe, yellow fruit is eaten. Finally, some fruits are left to sprout cotyledons that are eaten fried (16). More well-known tropical fruits include mango, papaya, guava, banana, pineapple, coconut, avocado, and breadfruit.

Amidst all the greenery of the forest exists a great variety of edible **vegetables and foliage.** An estimated 500 species are used in Africa alone (13).

Forest rivers, coastal areas, and mangrove forests harbor an abundance of **fish, crustaceans, and molluscs** that make significant contributions to local diets.

Wild **animal protein**—from mammals, birds, reptiles, amphibians, and invertebrates—contributes to diets in many cultures. Rodents and ungulates are particularly common meat sources.

Palm oil is produced from the fruit of wild palms. The trees also supply palm wine and fibers. A forest species with great potential for oil production is *Raphia* palm, which thrives in swampy, high rainfall areas. Other species, including the tallow and neem trees also are, or could be, sources of oil products (16).

Honey and wax production is another function of the forests that provides essential products for local populations. The introduction of modern beekeeping methods could expand this use with only moderate inputs.

Nuts are a common and protein-rich food source in forests important both locally and for trade. Betel nut, cashew nuts, and Brazil nuts are examples.

Game Ranching[1]

About three-fourths of the citizens of Zaire and Ghana rely on wildlife as their main meat source (4)—a situation common in some other tropical nations. As pressures on wildlife populations and habitats increase, more attention is being given to the idea of game ranching. Problems could arise, however, because creating commercial markets for these new food sources could induce subsistence gatherers to exploit wild game for income. Unless these activities are carefully regulated, this could result in overexploitation of wild game.

Husbandry of indigenous wildlife offers some potential to provide incentives to sustain the quality of dry open forest and shrubland habitats where most ungulates are found. Native wild species generally are adapted to their natural environment and, thus, tend to require less water and be more resistant to disease than exotic livestock. Native species thrive on local vegetation and typically may be better suited to arid and semiarid ranges than conventional livestock. Further, native species' efficiency of food use usually compares favorably with livestock (19). In national parks of Zaire and Uganda, for instance, each square kilometer of land can support 24 to 37 tons of wildlife (10 species) compared with only 3 to 5 tons of cattle (23).

Much remains to be learned about the husbandry of wild species. Further, there are drawbacks to this technology. Wild meat can contain parasites, making inspection for commercial markets a problem. Initial costs to acquire, stock, fence, and manage a range of adequate size can be high, and questions remain about whether such operations can be profitable and sustainable. However, in time game ranching might be developed to act as an incentive to preserving wild species and their habitat.

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[1] See *Water-Related Technologies for Sustainable Agriculture in Arid/Semiarid Lands: Selected Foreign Experience—Background Paper* (Washington, D.C.: U.S. Congress, Office of Technology Assessment, OTA-BP-F-20, May 1983), for more information on game ranching in Africa.

Innovative Forest Products

A wide variety of forest products that are not now harvested or are only gathered on a small or subsistence scale might have commercial potential. Development of markets for such products can provide income for rural people, thus reducing their need to overexploit forest resources, and can provide incentives to protect wild populations and their habitat. To develop these alternative forest products, wild breeding populations must be retained, habitat managed, and gathering activities regulated.

Papua New Guinea is a forerunner in efforts to take advantage of tropical forest biological resources. Much of Papua New Guinea remains covered by undisturbed tropical moist forest, and exploiting the economic value of its organisms is helping to safeguard this habitat. Papua New Guinea has developed management systems to domesticate, propagate, and harvest cassowaries (for feathers), megapodes (for eggs), wallabies and deer (for meat and hid[illegible], and a number of other species. Because insect collection is profitable, the government has declared insects a national resource and is the only country in the world to specify insect conservation a national objective in its constitution (23). These projects demonstrate a strategy that could be applied in other areas or to other organisms.

Production strategies dependent on wild breeding populations of threatened species face a serious constraint. Unless expansion of the

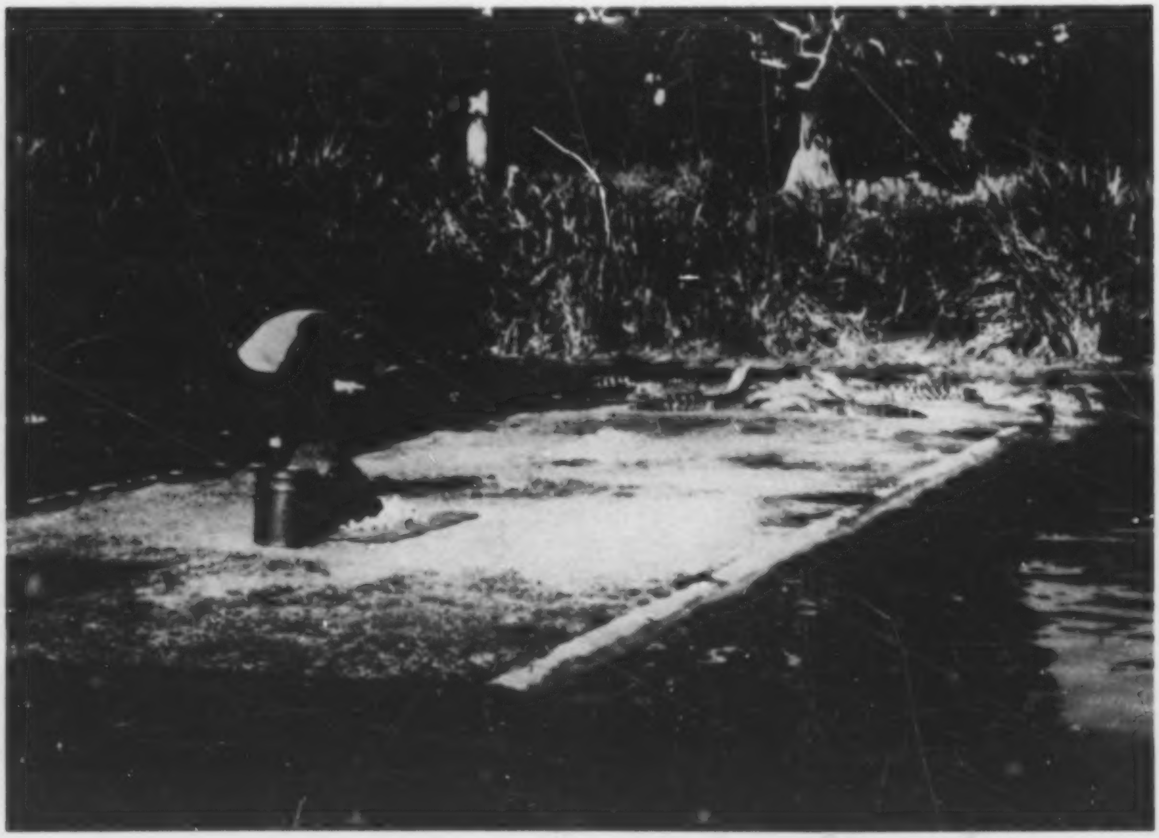

Photo credit: National Academy of Sciences

Crocodile farming in Papua New Guinea shows potential as a technique that can provide direct economic benefits while encouraging protection of tropical forest resources

Examples of Innovative Approaches to Tropical Forest Resources Management

Butterfly farming is an example of development of a commercial product from an unusual tropical forest resource. Once thought of as pests if common, or collector's items if rare, butterflies have become a profitable forest resource for villagers in Papua New Guinea. Butterflies provide a high value, low capital outlay investment: no tree clearing, fences, or veterinary services are required. Each year, millions are sold to museums, entomologists, craftspeople, and collectors. Collectors have paid as much as $1,000 for a specimen of the brilliantly colored birdwing butterfly.

A system of management has been developed to control the production and exploitation of this resource. Villagers attract butterflies by planting preferred flowering shrubs around the edge of fields. Nearby, they plant the leafy plants that the caterpillars eat. The combination provides a complete habitat for the butterflies' lifecycle. The farmer simply harvests specimens as time and demand allow. Because the butterflies are collected under relatively controlled conditions, they typically are of higher quality than wild-caught specimens. Consequently, the demand for poached specimens is reduced.

Some 500 villagers are rearing or collecting butterflies, beetles, and other insects for export. The government has established an insect farming and trading agency to help market insects to overseas buyers. Profits return to the villagers. Because the program relies on healthy wild populations to keep the farms stocked, it provides an economic incentive to preserve forest habitat.

Crocodiles also are raised for profit by villagers in Papua New Guinea. Loss of forest habitat often exerts great pressure on forest wildlife, particularly the large predator species. In an innovative experiment in Papau New Guinea, a management scheme has been developed to counteract this trend—and produce benefits for local villagers, crocodiles, and, indirectly, forests.

Crocodiles in the wild lay between 30 and 70 eggs each year, but few of those actually survive to reach breeding size. Commercial hunting garners some income from the species, but threatens breeding populations because hunters seek the biggest specimens. Recognizing that a ban on hunting would be unenforceable and unpopular, the government restructured trade to discourage the shooting of breeders and encourage exploitation of the hordes of tiny hatchlings. They banned the sale of large skins, while assistance agencies helped to develop a management system to collect hatchlings in the wild and raise them to marketable size in captivity.

The scheme, though not without problems, shows some success. Crocodiles are raised for a year or two and sold by villagers for up to $100 each. (Young crocodiles have a better feeding efficiency than livestock: 1⅓ lbs of food gives 1 lb of weight gain, while conventional livestock requires 5 to 8 lbs of food for 1 lb of weight gain.) Crocodile production brings Papua New Guinea $4 million in foreign exchange each year. Because the program is based on harvesting young hatchlings from the wild, the economic value of the wild populations and their habitats becomes apparent. It gives a tangible, economic value to wildlife protection.

SOURCE: N. Vietmeyer, "Underexploited Plant and Animal Resources for Developing Country Agriculture," *Background Papers for Innovative Technologies for Lesser Developed Countries*, Office of Technology Assessment workshop prepared for the U.S. House of Representatives, Committee on Foreign Affairs, September 1981.

markets for nonwood forest products is accompanied by strict regulation of gathering activities and preservation of habitat, the opportunity for profit will induce people to gather without regard for maintaining the breeding populations. Animal populations may decline precipitously. This occurred, for example, in fruitbat populations on the U.S. Pacific island of Guam.

Fruitbats are a much sought after food source on Guam. But habitat destruction and overhunting have exhausted their populations to a point where one species is probably extinct and the other endangered. The demand for this delicacy, however, remains high and fruitbats are now being imported from islands in the U.S. Trust Territory, further increasing hunting pressure in these areas. On the island of Yap, fruitbats have cultural significance which in the past had limited their harvest. But the attraction of Guam's markets has increased illegal hunting and export. Hunters will shoot into nesting colonies, disregarding the wounded or lost bats. Thus, the indigenous Yapese fruitbat is being harvested unsustainably and may become extinct if management and enforceable regulation are not instituted.

Conclusion

Forest ecosystems house complex associations of vegetation, wildlife, and other potential resources. If methods were developed to use these nonwood forest resources more fully—either by discovering new, valuable products or by facilitating collection and processing of established products—some of the incentives for deforestation would be reduced and more forests might escape conversion to unsustainable uses.

To do this, some marketable advantage must be identified in the local environment, then developed to provide sustained economic returns. This process calls for improved management of the resource system, which best comes from using modern science to build on a foundation of traditional knowledge. But governments often have too little information on the long-term value of their forests and invest very little in development of forest products other than timber. U.S. expertise could be applied to this problem, especially from the fields of ecology, botany, business administration, and forest management.

The lack of development of nonwood forest products may result partly from the fact that nonwood and subsistence food products gathered from tropical forests have rarely been accounted for in economic analyses. Such products generally are used in subsistence economies and have no easily defined "market value." Where they are commercially exploited, it is in a marketing system so diffuse that the product flows are seldom measured. Improved assessment of the role of forest products in subsistence economies and improved development of markets for nontimber forest products could cause decisionmakers to associate greater value with undisturbed forests.

Creation of new markets for previously unused tropical forest plants and animals or expansion of local markets for previously underused products could present new opportunities to overexploit forest resources. Unless management and regulatory systems are instituted along with market development, wild breeding stock may be depleted to fill market demand.

The various opportunities that exist to increase the value of the standing forests offer significant benefits to people as well as to forests. The management systems under development in Papua New Guinea are examples of how such systems can provide employment opportunities, income for local residents, new sources of food or other human needs, and opportunities for exports and increased foreign exchange. Increasing commitments from U.S. and other assistance agencies to develop sustainable management systems and markets for nonwood products could act to alleviate a variety of social problems.

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Chapter 8

Technologies to Reduce Overcutting

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Chapter 8

Technologies to Reduce Overcutting

HIGHLIGHTS

Industrial Wood

- If the world demand for wood is to be met without eventually depleting all the accessible tropical forests, practical alternatives to cutting extensive areas must be developed.
- To implement alternative approaches, profitable technologies to harvest, process, and market a wider range of tree species and sizes must be developed. The U.S. Forest Products Laboratory has made and can continue to make significant contributions in developing such technologies.
- Intensive harvesting schemes, such as harvesting all merchantable-size trees from a narrow band of forest, need experimentation and evaluation for economic and silvicultural feasibility and environmental effect.

Wood Fuels

- Overexploitation of forests for firewood and charcoal is increasing. This could be alleviated by enhancing the efficiency of wood use and by substituting alternative energy sources.
- Improved stoves and more efficient charcoal production can conserve wood supplies, but effective technology diffusion requires extensive field testing and careful consideration of social and economic factors.
- Efforts to develop and apply nonwood renewable energy sources are uncoordinated and generally underfunded, but have considerable potential to reduce fuelwood demand.
- Widespread implementation of fuelwood plantation techniques is constrained by sociocultural and economic factors.
- Actions that reduce demand for fuelwood can also reduce incentives to invest in future wood supply. Thus, such actions must be planned carefully with respect to efforts to increase supply through fuelwood plantations.

INTRODUCTION

Exponentially increasing demand for wood for both commercial and fuel uses is contributing to deforestation and resource degradation in both undisturbed and secondary tropical forests. Industrial wood users will buy only a few of the many species that grow in tropical forests. As a result, extensive areas must be "selectively cut," causing severe damage to the unharvested trees and to the soil. The practice also opens extensive areas to inappropriate settlement by farmers. More species are used for fuelwood, but fuelwood is being cut much faster than it is grown.

Technical solutions to these problems include methods to increase the efficiency and intensity of harvesting industrial wood so that less extensive areas need to be cut and methods to make wood use more efficient so as to reduce demand.

INDUSTRIAL WOOD: EXPANDING NUMBER OF SPECIES AND SIZES HARVESTED

Background

If the world demand for wood is to be met without eventually depleting or degrading all the accessible tropical forests, alternatives to extensive selective cutting must be found. Tree harvesting and management on small areas can reduce the need to cut wood on other sites. This requires profitable technologies to harvest, process, and market a wider range of tree species and sizes than is the case today. Using a wider range of tree species could lead to destruction of tropical forests and the depletion of soil fertility.

Harvesting, Transporting, and Handling

Improvements in harvesting methods, transportation, and handling can make substantial contributions to the improved use and management of tropical forests. Likewise, the availability of technologies, the amount of planning, and the commitment to management all can reduce the logging damage to residual forests.

The residual vegetation left in a tropical forest after logging is often severely damaged—usually about 50 percent of the remaining forest is adversely affected. Considerable loss occurs during felling and extraction. Furthermore, about one-third of the logged area typically suffers erosion as a result of soil compaction by heavy equipment (6). A major improvement in harvesting practices is possible simply by matching the appropriate practice to particular site conditions to minimize environmental damage.

Intensive harvesting (clearcutting) of small areas reduces the number of roads built, and so reduces road-induced erosion and access by agriculturalists. If fewer roads are built, more capital could be available to improve existing roads and to purchase suitable trucks and hauling vehicles.

Clearcutting, on the other hand, could increase nutrient depletion and reduce biological diversity. Erosion is likely to be severe on clearcut sites during and immediately after logging, and if logging is followed by fire, erosion is even greater (6). In addition, the quality of secondary forests and their suitability for both economic use and as habitat capable of maintaining biological diversity are largely unknown. Intensive logging of tropical forests has significant adverse impact on animal life that is sensitive to microclimate and food supply changes. Other animals, however, can survive in logged forests (12).

Opportunities exist to experiment with various practices that would minimize negative impacts of intensive harvesting. A technique that warrants field testing is the harvesting of all merchantable size trees from narrow bands of forest followed by natural and/or artificial regeneration. If harvested strips are oriented along contours and kept quite narrow (approximately 100 meters), many of the disadvantages of clearcutting may be avoided. Animals still would have access to a large forest habitat, recolonization of plants from surrounding forest would be enhanced, and the soil microorganism populations, which play a crucial role in the physical-chemical properties of tropical soils, probably would be quickly reestablished after logging. This method, however, has economic and engineering drawbacks that limit its commercial appeal (7).

Harvesting technologies that can reduce forest damage include the use of improved cable logging systems, hand tools, self-loading trucks, and large skidder vehicles to reduce the need for crawler tractors. Efficiency in handling can be improved if equipment is selected to match the character of the particular site.

Simply applying existing knowledge about the transport and storage of logs and lumber could reduce losses from mold, stains, insects,

Photo credit: Dr. Miedler, FAO

Selective logging to remove only the most commercially valuable trees can lead to resource degradation because the remaining trees are typically damaged by felling and extraction operations. Also, as more roads are built, erosion problems increase and new areas are opened to shifting agriculturalists

splitting, decay, improper drying, and damage from poor handling practices (32). At present, large quantities of logs deteriorate at roadsides. This occurs in Burma, South India, Bangladesh, and other places where roads are impassable during the rainy season (11).

To encourage responsible management, tropical countries could institute longer term licensing agreements with logging concessions, together with tax incentives. With longer agreements, for instance, operators would have incentive to build roads to a higher standard because they could amortize the costs over two logging cycles (11).

Use of More Tree Species and Sizes

Markets

A variety of factors—some biological, some commercial, and some logistical—interact to determine how intensely a forest is exploited, including the composition of the forest, the form of the trees, and character of their wood (11). Selective logging is common in closed tropical hardwood forests in part because use of such forests has been export-oriented. Export markets require large quantities of a uniform product, preferably a single species of good appearance. Thus, very few species and only large logs were acceptable.

When only select individuals of a few tree species are logged in most tropical forests, forest resources are degraded. This damage could be reduced if more species were used and if the size and form criteria were less limiting.

Considerable research has been conducted on lesser known tropical tree species. The physical and chemical properties of tropical timbers are assessed according to their wood processing use. However, the results of this work are scattered and frequently unknown to wood users (26).

Many lesser known tree species have disadvantages that are difficult to overcome, such as poor form, extreme hardness or abrasiveness, unacceptable loss of quality in drying, and lack of durability (11). The rectification of these features can be costly. Thus, importing countries are reluctant to take such species when well-known tropical woods and temperate softwoods are available at acceptable prices.

Standardized descriptions of wood properties and units of measurement, together with some classification system that distinguishes degrees of suitability for specific purposes, are basic marketing requirements. Standardization and grading are complicated because wood products have a great degree of variability and versatility. Inadequate lumber standards contribute to inefficient tropical lumber marketing and use in both producing and importing countries. Without a grading system directed toward efficiency of use and without prices that correspond to quality, the tendency is for local wood users to demand higher quality material than the end use requires. This puts added demand on forests for high-quality material and often unnecessarily removes tropical forest products from export markets. It also limits local markets from fully using lower grade lumber and contributes to high prices (26). Thus, improved standardization of dimensions and grades could minimize waste, reduce product cost, and increase the profitability of intensive forest management.

A prospect for increasing the use of lesser known species and smaller trees is to group species according to their capacity to meet specific end use requirements—e.g., group all species suitable for construction material together (11). Species could then be marketed by group instead of by species name. But first, performance requirements for various end uses must be identified and systems of matching properties to those requirements must be developed.

Firms in Australia and Great Britain are experimenting with end-use grouping of timber. The Australians devised 12 general end-use categories, each referenced to a well known and widely used wood species to compare new species or species groups with the reference wood (14). The British classification system is more elaborate. It identifies the specific wood properties required for each major wood use and identifies the available timbers with required properties at acceptable and preferred levels. Flexibility is provided by indicating special processing technologies that can be applied to species rated below the preferred level. Timber lists can be expanded as available timbers with established properties become available (4).

In the short term, the end-use approach may be better for local timber markets in tropical countries, particularly in those countries where the forest resources are small or have been depleted. Demand from the export market will come when other sources cannot meet the price, quantity, and quality specifications (11).

Preservatives

Some tropical woods with generally satisfactory physical properties are not used, or they give poor service, because they are susceptible to attack by termites, other insects, or fungi. For example, the sapwood of many durable species is perishable and usually is cut away. With smaller size trees, the portion of sapwood is greater and the waste in conversion is often so large that they are not used.

Many wood preservatives are available, together with a range of techniques for applying them, to counter different degrees of hazards. Some of these technologies—e.g., impregnation with creosote through pressure cylinders—are effective for timber in contact with the ground. But they require considerable expenditure on equipment and chemicals, and creosote is now difficult to obtain. Other techniques, such as pressure treatment with water soluble copper-chrome-arsenic compounds, though less costly and suitable for wood in some forms of construction, are still considered expensive (11). This confines their application to public works and to higher cost construction.

Simple and inexpensive preservative treatments for wood used at the village level and in low-cost urban housing need to be developed and promoted. At the village level, the social and economic benefits of wood treatment could be considerable. In the hot, wet Tropics, a treatment that increases the life of a simple wooden house from 5 to 10 years could reduce by half a villager's time spent on building and rebuilding (17). For simple techniques that already exist, information is needed on the performance of wood so that cost effectiveness can be evaluated (18).

Processing

The use of smaller sizes of both currently desirable tree species and of lesser known tree species raises some problems. For example, sawmills in tropical countries are often designed to deal with large logs. Output and profits from existing facilities would be reduced if small logs were used.

Investments are needed in equipment for small log sawmills and for separate, small log lines in the mills normally used for large logs. Machines for sawing small logs are available and could be manufactured locally in many tropical countries. Existing machines and mill designs need to be appraised, tested, and demonstrated. A further contribution could be made by installing small sawing and planing machines that convert defective material into small dimension stock for furniture, joinery, and flooring, thus reducing waste (11). In the Philippines and Sri Lanka, low-cost solar heated kilns designed by the U.S. Forest Service Forest Products Laboratory have demonstrated the ability to reduce waste in drying.

The percentage of high-density wood in tropical forests exceeds that from temperate forests. However, most processing technologies were developed in the temperate countries. Thus, processing technology will need to be modified to accommodate high density timbers as a wider range of tropical tree species is used.

Milling close to the harvesting site is another way to reduce waste. Portable sawmills are relatively inexpensive compared with equipment for permanent mills. However, existing portable machines include heavy components that are difficult to handle. Also, by reducing the inaccessibility of forests to processing centers, it could allow deforestation in areas now untouched by commercial loggings.

An important development would be the use of a small unit set up to mill logs at the stump. Milling at the stump, and transporting the timbers to roadside manually, could be more profitable and cause less environmental damage than hauling logs to mills. Such mills for use at the stump are still in the research and development stage.

Great progress toward making intensive harvesting profitable has occurred where multi-species wood chips are produced for wood pulp or fuel. The market for wood chips from tropical hardwood forests has been limited because softwood chips, which come mostly from temperate forests, make better paper. However, a new papermaking process promises to increase greatly the world markets for hardwood chips. This is the "press-dry paper process" developed at the U.S. Forest Products Laboratory. The process is successful on a pilot-scale, and U.S. firms are working to develop it on an industrial scale. When that is done, a decade or more should still remain before markets for tropical wood chips are greatly affected because of the long investment lag in paper mills.

If in the meantime forest departments can develop management and enforcement technologies to complement the opportunities for clearcutting, the impact on tropical forest resources could be beneficial. Otherwise, this technological breakthrough could result in increased deforestation.

Conclusion

Fuller use of the tropical forests can lead to increased revenues per unit area of forest cut and to development of a wide range of rural industries, including construction and manufacture of furniture and agricultural tools. Use of many tree species and sizes can supply growing domestic markets without reducing foreign exchange earnings from export.

Current logging practices are often environmentally destructive and wasteful. Yet existing technologies for harvesting, transportation, and handling methods could substantially improve management of tropical forests. Some of these have been developed in the United States, and U.S. expertise could play a significant role in the continued development and promotion of these technologies.

Intensive harvesting that would accompany fuller use of tropical forest trees could result in reducing the areas degraded by extensive logging. Enforcement of strict regulations regarding road building, site protection, and forest restoration would be more feasible if the amount of land to be regulated were reduced. However, without strict enforcement of such regulations, intensive harvesting could prove far more destructive than current practices.

Efforts to market a greater variety of tropical timbers are increasing. Much, however, remains to be done. Some species have characteristics that make them difficult and costly to harvest and process and that severely limit their end-uses. For such species and for forest residues, improved technologies and markets are needed for products for which species, size, and shape are not critical (e.g., charcoal, wood chips for pulp, and reconstituted wood panels). For poorly known but potentially marketable lumber species, the emphasis should be on more efficient technologies for processing and for improving use characteristics (preservation and drying) at an acceptable cost, and on marketing techniques, such as grouping of species by end-use requirements.

Although preservative treatment can and does expand international marketability, it is particularly important in moist tropical nations where wood deterioration is greatest and where wood substitutes are often used because of this problem. More consideration needs to be given to preservation technologies that are cheap, technologically simple, but effective.

WOOD FUELS

Background

Although wood is the fourth largest source of fuel in the world (after petroleum, coal, and natural gas), knowledge regarding its production and consumption is very imprecise. Most fuelwood is used in tropical nations, and for many it is in short supply. This is a hidden energy crisis. It does not enter GNP accounts and statistics on it are poor for several reasons. Wood often is gathered locally by users rather than being marketed. Even where it is marketed, it is often collected, without payment to landowners, from trees and shrubs near roads, around houses, on farms, or in poorly policed public forests. Fuelwood gatherers often take limbs rather than felling whole trees, so quantities taken are difficult to estimate.

Thus, much of the wood fuels data available for country-level planning and policymaking come not from actual measurements but rather from multiplying the population size times per capita consumption figures derived from small sample studies. In some cases, the source of the consumption figures cannot be found, much less checked for accuracy.

The ability to design and implement effective policies and projects for solving the wood fuels problem requires a thorough understanding of local consumption patterns and production possibilities. Many wood fuel projects of development assistance agencies and national governments have been unsuccessful because insufficient effort was devoted to studying these factors in advance (22). Fortunately, interest in wood fuels has increased greatly in the past decade. More studies are being done and the estimates of wood fuel use are improving. FAO's Forestry for Local Community Development Programs has recently published a useful collection of such studies (9).

Approximately 80 percent of the estimated 1 billion cubic meters (m^3) of wood removed annually from tropical forests is used for fuel (27). Thus, the sustainability of wood fuel production is inseparable from the sustainability of tropical forests. Whereas in the past fuelwood has been gathered mostly from natural stands, in the future it must come increasingly from tree plantations (30). The rate of tree plantings for firewood production throughout the world will have to be increased at least fivefold if fuelwood shortages are to be eased (8).

Three categories of actions could affect the imbalance between the demand and supply of wood fuel products:

1. Actions that directly influence the present and future demand for wood fuels (e.g., introduction of improved wood use or conversion technologies and substitution of nonwood-based energy sources).
2. Actions that affect the production of wood for fuel and, thus, reduce the pressure on natural stands (e.g., woodlots, plantations, and integrated land-use management).
3. Actions that do not directly affect production or use of woodfuel products but that have an impact on the socioeconomic conditions of the population drawing on forest resources (e.g., population, land tenure, etc.).

The third category influences the wood fuel situation only indirectly and is beyond the scope of this assessment, even though in the long run it may be the most important.

Technologies

Fuelwood and Charcoal Conservation Technologies

Four-fifths of the fuelwood consumed in developing countries is used for domestic purposes: cooking, space heating, and hot water (27). The form of fuel chosen, and method of use, can affect the total amount of wood consumed. For instance, many traditional cooking stoves and open fires use wood inefficiently because they focus the flames poorly on the cooking surface or give relatively incomplete combustion. Most stoves or open fires in tropical areas deliver only 5 to 15 percent of the fuel's energy content to the food being cooked (15).

Charcoal production is also energy inefficient. Traditional earth-covered pit or mound kilns can require 10 tons of air dried wood (15 percent moisture) to make 1 ton of charcoal

Photo credit: OTA staff

The three-stone fireplace—shown here in the Philippines—wastes much of the heat from the wood, but has esthetic and cultural appeal that inhibit acceptance of enclosed stoves

(24). Because a ton of charcoal has roughly three times the energy content of a ton of wood, this equals about 30 percent energy conversion efficiency (27). However, this loss is offset somewhat because traditional charcoal stoves tend to be more efficient than traditional wood stoves.

Reducing heat losses during conversion of wood to energy, including during conversion to charcoal, can conserve wood supplies. In other cases, simply changing from open fires to stoves increases efficiency. In many cases, fuelwood savings can be realized simply by drying (seasoning) wood before burning (27). Moist wood produces only half as much heat as air dried wood. However, this seemingly simple change may not be feasible where termites and fungi infest wood rapidly; or where there are heavy, frequent rains; or where people cannot afford to purchase or store an inventory of wood.

Improvements in stove design could reduce wood requirements fivefold to tenfold by increasing stove conversion efficiency from the 5 to 10 percent achieved now to an efficiency of 20 to 30 percent (20). Improved stoves typically are designed to provide better draft and more complete combustion and to concentrate heat on the cooking surface. Most improved stove designs use various insulating materials—for instance, a ceramic or clay-vermiculite lining—to reduce heat loss through the stove walls. In addition to increasing the efficiency of wood use, the wide dissemination of such stoves, if properly maintained and used, could reduce the time, energy, and money that tropical country women now spend collecting fuel (20).

More than 100 stove models, both traditional and experimental, are described in a recent compendium of stove designs (5). These stoves represent a broad spectrum of candidates for improving fuel-use efficiency. For example, the Lorena stove used in Guatemala can cut fuelwood consumption in half. It is molded from mud and sand, fitted with a metal damper and pipe, and costs the equivalent of only US$5. The Indian Junagadh stove is also simple and cheap and is reportedly 30 percent efficient. It is made with bricks or mud to absorb more heat, is designed with a tighter fitting hole for the pot to reduce heat loss, and in some cases is equipped with a metal damper to control combustion (22).

Few such stoves, however, have been readily accepted by local populations. Acceptance is determined not only by fuel efficiency but by cost, simplicity of operation and maintenance, availability of materials, cultural preferences and patterns, and the mechanisms chosen to promote the new stoves. These factors vary from region to region, so a stove designed in one place may not be accepted or used efficiently elsewhere (20).

Obtaining the widespread use of an improved stove design is more important than design details if the improvements are expected to have a significant impact on fuelwood demand. Many programs to design improved stoves have failed to meet expectations because they underestimated the economic and social constraints involved. Further, claims about efficient stoves have seldom been adequately documented. Thus, it is especially important to field test (onsite) a design before promoting its widespread use (19). A strategy to design and promote any new stove should include:

1. a survey of traditional cooking practices to ascertain sociocultural criteria that the stoves must meet,
2. field testing of existing stoves,
3. assessment of alternative designs,
4. laboratory testing of alternative designs,
5. design work or modification of existing stoves,
6. limited, followed by extended, field testing of the improvements, and
7. national or regional extension programs and support (13).

Introduction efforts have focused on low-cost, owner-built stoves. Two models that have achieved some acceptance are the Louga stove (Senegal) and the Lorena stove (Central America and various African countries). Because a relatively lengthy period is needed for the initial promotion and for household training to build, use, and maintain the stoves, the extension/training cost per stove is high and the dissemination rate is slow (limited by availability, skills, and mobility of extension staff). Consequently, more attention is being given to using existing artisans and their marketing network to speed the dissemination process.

Charcoal production can be improved on a large or small scale. As traditional earth-covered kilns give way to improved designs, including kilns built of brick, concrete, or metal, there is better carbonization control, higher conversion efficiencies, and production of a cleaner end product. The conversion efficiency of a traditional earth kiln can be improved 50 percent at low cost simply through improved kiln operation: use of only dense, dry wood chopped into relatively uniform pieces; assuring that the wood is packed as tightly as possible; assuring the earth covering the kiln is sufficiently thick to prevent complete combustion; proper spacing of initial air vents; and careful monitoring of combustion and later carbonization conditions (27).

At minimal cost, flattened metal cans or other scrap sheet metal can be inserted between the stacked wood and the insulating earth layer, reducing dirt contamination (which in some kilns reduces the efficiency of 20 to 30 percent of the charcoal produced) (27). More sophisticated designs and building materials (brick, concrete, or metal) can be even more efficient but may require substantially higher capital investment.

A relatively expensive alternative is the portable steel charcoal kiln, which consists of two cylindrical steel shells, a conical lid, and four chimneys. It has been used throughout the world for many years. The chief advantages of such kilns are ease of operation, increased rates of recovery (15 to 20 percent), relatively short production cycle (72 hours), and relative portability (by truck or animal-drawn cart). The high capital cost makes it prohibitively expensive for traditional producers who do not reap much economic benefit from improved conversion.

However, these kilns have been used successfully in conjunction with large-scale agricultural land clearing and on large plantations where periodic portability is desired. For example, the "Char-Lanka" project in Sri Lanka takes advantage of an expanding market for charcoal to make beneficial use of the timber cleared from a large agricultural development project area. A major U.S. bank helped finance both small-scale artisans to fabricate portable metal kilns and small-scale charcoal producers to lease such kilns. Eventually over 200 kilns will be built locally (27).

In some tropical countries, charcoal already accounts for a significant fraction of total wood fuel use and it is increasing its market share, particularly in urban centers. Given the low conversion efficiency of most charcoal production, the increasing substitution of charcoal for wood with its attendant energy losses will exacerbate problems of wood supply/demand imbalance.

Because most charcoal is produced part-time by small cottage industry laborers, many or most of whom operate illegally or extralegally, it is particularly difficult to launch national or regional campaigns to improve charcoal production efficiency. Char-Lanka is one potentially promising model that could help small-scale kiln producers function more effectively. The Peace Corps and others sponsor many local efforts to improve traditional charcoal producers' operating efficiencies, but so far substantial improvements in forest resource depletion rates have not been demonstrated.

Resource Substitution

Resource substitution can be used to protect forests in two ways: by substituting alternative energy sources for fuelwood, or by substituting fuelwood cultivated in plantations for fuelwood collected from natural forests. Nonwood energy substitutes can be conventional (kerosene, electricity, or natural gas) or innovative (solar, wind, small hydro, or biogas). Detailed analysis of these technologies is outside the scope of this assessment.

Substituting Nonwood Fuels. Through the 1950's, 1960's, and early 1970's, large-scale shifts occurred from traditional fuels (wood and charcoal) to petroleum fuels—primarily kerosene. It is unlikely, however, that substitutions will usurp the primary place of fuelwood in developing countries while wood resources still exist. Further, it is unlikely that financial subsidies of such fuels can continue indefinitely. However, such subsidies can be a way to achieve important temporary reductions in wood demand, while the productivity of natural forests is recovering or while fuelwood plantations are being established.

Many efforts to develop and apply alternative energy sources are under way worldwide, but they seem to be widely scattered, uncoordinated, and generally underfunded (32). Actual adoption of these technologies is constrained by their financial and managerial feasibility and by the enormous logistical difficulty in changing the habits of millions of dispersed and often isolated villagers. The substitution of various forms of energy for fuelwood by these people probably will be influenced largely by changes in their lifestyle, standard of living, the location of their settlements, and access to available technologies. Conscious policy decisions to affect fuelwood consumption, production, or substitution will have a much greater prospect for success if the policies build on the energy and economic changes already occurring throughout the rural areas of the Tropics (27).

Still, the energy demand/supply imbalance must be met mainly through improving the supply, distribution, and use of fuelwood and charcoal. A preparatory committee for the U.N. Conference on New and Renewable Sources of Energy concluded that there is "no alternative source of energy that could provide a viable substitute for fuelwood on a scale which could permit a major reduction in dependence on it by the world's poor in the next quarter century. Their poverty, and the remoteness of many of them, will inescapably remove other energy sources from their range of possibilities" (31).

Fuelwood Plantations. The idea of growing fuelwood in plantations is not new. But there is not extensive technical experience growing trees for firewood because foresters traditionally have planted trees primarily for timber and pulpwood (19). Most fuelwood produced from plantations is used for cooking, with some for heating and charcoal manufacture. Some large-scale plantations do, however, supply fuelwood for industry and transportation.

Three different types of plantations can be envisioned: plantings by individual farmers, more concentrated village woodlots, and large-scale plantations for concentrated demand.

Individual plantings—Increasing emphasis in forestry development programs has been focused on technologies aimed at bringing rural populations into direct participation in forestry and fuelwood production projects. This can include farm forestry, where individual farmers grow just enough trees for their own fuel needs or for a cash crop, and agroforestry, where trees are combined with food-producing systems in the form of shelterbelts, windbreaks, or more complex mixtures.

Individual tree planting can make use of otherwise little-used areas. Because wood for fuel need not be large, fast-growing and coppicing shrubs can be used along roads and field edges. Multipurpose trees that provide fuelwood as a byproduct of food or forage production may be accepted even by rural people with little land. Where water is adequate and a market for fuelwood exists, closely spaced plantings of fast-growing, coppicing shrubs or trees can be grown on relatively small areas to both provide domestic needs and generate income.

In many countries, fuelwood is becoming part of the market economy providing farmers with income that offsets the costs associated with establishing or maintaining tree cover for environmental stability or rehabilitation. Tree planting by individual farmers in Gujarat, India, has spread to such an extent that the 50 million seedlings distributed by the Forestry

Photo credit: OTA staff

Eucalyptus fuelwood supplied by Farm Forestry Projects in India. Farmers are encouraged to plant trees to supply their fuelwood needs as well as provide income from sales

Department in 1980 (equivalent to an annual planting of at least 25,000 ha) were insufficient to meet demand (22).

Village Woodlots—Village or communal fuelwood plantations are larger in scale than individual plantings. Management of these plantations resembles conventional forestry in many respects, except that even existing low-quality coppice trees are exploited. Trees may be multipurpose or for energy production only. Rotations vary between 5 and 30 years, depending on species and site conditions. Because the area cropped generally is larger than where trees are in individual holdings, and because the land is dedicated entirely to tree crops, harvesting techniques can be similar to those used in conventional forestry.

The management techniques for many species suitable for village woodlots are relatively well-known. But sociocultural and economic problems can affect acceptance. Constraints that can impede village forestry include:

- heterogeneous social structure that hinders village-level decisionmaking and cooperation;
- competition with other village priorities for limited village resources;
- loss of whatever production currently comes from the woodlot site (especially grazing);
- lack of government and forestry department support for promotion, extension, free seedlings, technical advice, etc.;
- lack of an institutional structure to define ownership and distribution of woodlot products;
- shortage of labor for plantation maintenance; and
- tendency of foresters or other outsiders to dictate what species to use in village woodlots with too little consultation with villagers, especially women, who are most likely to tend, harvest, and use woodlot products (22).

Too little is known about how village people make decisions about land use, land tenure, and tradeoffs in production of different goods and services. In a World Bank project to establish 500 ha of village woodlots in Niger, for example, village people either pulled out seedlings as fast as the trees were planted or allowed uncontrolled grazing to take place. The villagers had not been involved in formulating the project and perceived the woodlot area as a traditional grazing ground (22).

Trees in some fuelwood plantations (e.g., *Eucalyptus camaldulensis*) in some Sahelian countries have not been well accepted locally. Fast-growing plantations generally supply fuelwood only. But the native brushland they replace also supplied other products such as gums, medicines, food, and forage. In some cases native brush could be managed to maximize fuelwood production while sustaining production of other products. One opportunity is in-

Photo credit: OTA staff

This 2-year old, irrigated *Leucaena* woodlot in Gujarat, India, shows multipurpose legume trees grown in village woodlots for fuel, forage, and building materials

terplanting native brushland with fuelwood-producing, nitrogen-fixing shrubs. Development of such systems will require more research on subjects such as management techniques and species compatibility (2).

There is no complete package that can be universally applied to encourage participation in a village woodlot program; each must vary according to the needs and priorities of a village. Several general guidelines can be extracted from recent experience. For village woodlot programs to succeed, there must be: 1) strong government commitment to village forestry, 2) perception of the forestry department's role in rural forestry, 3) villager participation (especially village women) in program formulation, 4) understanding of village perceptions, priorities, sociocultural framework, and economic needs, and 5) design of a program understandable to village people that caters to their needs and provides incentives effective within the particular sociocultural framework (e.g., improved agricultural practices, monetary incentives, improved infrastructure, employment) (22).

Industrial fuelwood plantations—Although much more wood is consumed for household use in tropical countries, wood fuel used for processing and service activities is still very substantial. According to available surveys, these uses account for between 2 and 15 percent of total wood fuel use in Africa and Asia. Though some of these uses are scattered (e.g., charcoal for commercial food preparation, firewood for brickmaking and cement), others give rise to vary large demands concentrated in single locations or small areas. For example, tobacco-curing is estimated to have required 1.1 million m^3 of fuelwood in Tanzania in 1970 and, together with rubber preparation fuelwood, nearly 300,000 m^3 in Thailand (23). Industrial demand is growing much faster than household demand (3).

In Brazil, about 2 million ha of plantations produce an estimated 3 million tons of charcoal from *Eucalyptus* wood to support the country's metallurgical industry. The planted area is expected to exceed 4 million ha by the year 2000 (16). In Kenya, large-scale charcoal production is a byproduct of the use of bark to produce tanning extract.

Recently, opportunities to run factories on wood have been enhanced by the availability of wood chips and pellets. These standardized forms are more convenient to store and use than logs or split wood and, thus, are gaining acceptance as a source of industrial energy. High-speed chipping machines have been developed that make standard, matchbox-sized wood chips and then shoot them into a waiting van. The chips are suitable to use in woodfired boilers for industrial applications. Wood-chip machines are especially advantageous alongside logging operations, since they can make a useful product from the debris left by loggers. Wood chippers also can cull old, diseased, or contorted trees from forests managed for timber.

Wood chips are bulky and contain about 50 percent water so they cannot be profitably hauled over long road or rail distances for use as fuel. Wood chips can be transported over long distances by ships, however, as the per mile cost is relatively low. Wood pellets are smaller than wood chips; they are made from wood waste bound together under heat and pressure. These can be used in coal or charcoal furnaces without modifications. Since pellets are drier and denser than wood chips, they can be transported economically over greater distances. The use of wood chips and pellets is confined largely to North America, but the practice is spreading to other countries (30).

Large-scale energy plantations are also used by forestry agencies to protect timber reforestation sites and protected areas from illegal fuelwood gathering. In Indonesia, 34,000 ha of *Calliandra* have been established as a buffer zone around national forests to protect the natural trees from fuelwood gatherers.

The removal of trees for fuel eventually can exhaust the soil. In energy plantations, the nutrient drain may be more severe than in conventional timber plantations because younger trees contain a proportionately larger share of some nutrients. Furthermore, wood chipping machines shred leaves and twigs as well as trunks and branches. This depletion could be alleviated in industrial energy plantations by spreading furnace residues around the trees. Nitrogen fertilizer would still be required for trees that do not have nitrogen-fixing microorganisms. Growing several kinds of trees in plantations could alleviate some of the wildlife disruption problems. In theory, this and the use of indigenous species could also make plantations less susceptible to catastrophic damage by insects and disease.

Eucalyptus, Acacia, Calliandra, Leucaena, and *Prosopis* are among many potentially useful trees that are beginning to be used in plantations, village woodlots, and individual sites (20). The trees most likely to prove useful for fuelwood plantations are fast-growing species that can withstand degraded soils, exposure to wind, and drought (20). The ability to coppice (regrow from cut stumps or root suckers) is important for fuelwood species because this allows repeated harvest without the cost and effort of replanting. For example, *Leucaena leucocephala* is a legume tree that supplies fuelwood, fodder, and timber and enriches the soil. On favorable sites yields of 40 to 100 m^3/ha/yr can be expected from selected strains of *Leucaena*. These trees can be harvested every 3 to 6 years and the seedling generation rotation can be followed by three or more coppice generations, all of which give comparable yields (21).

To achieve sufficient profits at all levels, from farm forestry to large-scale projects, the average net energy harvested needs to be high per area and per time unit. Since labor costs may be formidable, productivity must be sufficiently high to make product prices competitive with available commercial fuels. But high productivity usually needs high-quality land. This can lead to conflicts between wood fuel production and food production (29).

The following types of land are likely to be most readily available for forestry because they are least in demand for agriculture: abandoned farmland, low-grade coppice forest, sedge or cane-growing coastal or riverine areas, saline land, mountain slopes, dry areas; sludge deposits, other types of unproductive land. Few of these are suited to high-input, short-rotation forestry. In many cases, low-input, fuelwood forestry may offer a better prospect.

Unless it is clearly profitable within a few years, growing wood for fuel, whether on a large or small scale, demands social and political commitments that may be difficult to obtain and maintain. High investment costs for fuelwood plantations also serve as a disincentive. In areas where substantial forest or brush cover remain, it is cheaper to harvest wood from the forests (even though they may be badly overcut) than to pay for plantation-grown wood.

Gathering wood from natural forests, as long as they remain, requires no investment outlays. In such situations, fuelwood plantings are more likely to succeed if natural forests are protected from cutting and if plantations provide additional marketable products, serve some additional desired function, or are integrated with agriculture. In areas where no natural forests remain within a considerable radius of a town, village woodlots or wood fuel plantations can be highly profitable.

Evidence throughout the developing nations shows that cash incentives are among the most widely and readily received. Recent studies have shown that the economic and financial (primarily cash) benefits of tree growing derive from products other than fuelwood (25,28) and that the increased availability of fuelwood is almost always a *byproduct* of stepped-up tree growing for other purposes. In other words, although it may be socially worthwhile to plant more trees, the incentives to do so will be influenced by how well those trees serve as income-producing assets (28). Increased supplies of fuelwood, therefore, may be best promoted by recognizing the secondary financial importance fuelwood holds relative to other forest products (27).

Development or expansion of fuelwood markets, however, may induce relatively powerful villagers or people from cities to gain control of fuelwood supplies. This would then deny landless people access to needed subsistence resources (1).

Conclusion

The rate at which forests are converted to other, less sustainable uses can be reduced by decreasing the demand for wood. This can be done by enhancing the efficiency of wood use or by substituting alternatives for wood from foresters.

The efficiency of domestic wood use can be improved through better stove and kiln technologies. Since most fuelwood and stove projects have been initiated only recently, it is premature to stipulate which techniques are most likely to achieve widespread diffusion. Several observations, however, can be made.

- To develop effective methods of technology dissemination, high priority must be given to social and economic research and to field evaluation of the technologies.
- Farmers, artisans, and entrepreneurs are most likely to adopt and spread improved techniques for wood growing, charcoal production, and stove design if they can profit from the improvements through existing market channels.
- Improvements in charcoal production should generally be introduced as incremental changes in existing methods.
- Dissemination strategies for fuelwood technologies must take into account the differences in male and female roles and incentives as they relate to how house-

holds' land and labor resources are used, who makes purchase decisions, who benefits from alternative tree products, etc. (27).

- The greatest potential for farmers to profit from tree growing comes not from single-purpose fuelwood plantations but rather from sale of other forest products, for which market development may be needed, and from agroforestry, which not only produces wood but also improves yields of associated crops.

Improved stoves may reduce the range of fuels that can be used, may be too expensive, or simply may be outside the abilities of local craftsmen. Improved charcoal production does not necessarily lead to expected reductions in the wood consumed to make charcoal. Unless there is an effectively enforced ceiling on the exploitation of woodlands, charcoal makers may use the time they gain from using more efficient kilns to make even more charcoal, thus accelerating the depletion of wood resources rather than slowing it.

Securing future wood supplies is a political, economic, and social problem. It is affected by problems of land ownership, local customs, and social organization. Until these are resolved, measures to reduce demand will fail to reach the root of the problem. Demand reduction creates no incentives for increased supply; it may even achieve the reverse. Where fuelwood has sufficient commercial value above the cost of harvesting and transport, it is more likely that someone will be prepared to invest in planting trees (10).

Interest and experiments in the use of small-scale, renewable energy technologies (solar driers, small hydropower, etc.) are widespread. Such technologies are not yet able to substitute for wood use, however, and their adoption is inhibited by economic and managerial constraints. Further, it will be difficult to achieve widespread adoption of these technologies because of the problems inherent in trying to change the long-held habits of large, diverse, and often isolated rural populations.

Similarly, substituting nonwood fuels (kerosene, bottled gas, electricity, etc.) for fuelwood has potential to reduce demand temporarily for forest wood while plantations are being established and while the natural forest is recovering. However, the costs of obtaining and distributing these fuels are often prohibitive. Subsidies to facilitate the adoption of nonwood energy sources may be necessary in regions of critical deforestation, but they cannot be seen as a long-term remedy. Substituting plantation-grown wood for natural wood is the more sustainable option for many tropical regions.

Tree planting is constrained where access to "free-for-the-taking" forest wood is not restricted. In such cases, people are unlikely to invest land and labor in fuelwood plantations even if other inputs are government-subsidized. The economic feasibility of fuelwood plantations can be improved if they also are designed to provide marketable products other than woods, such as fodder, or to provide some additional service, such as shelterbelts. However, even in these cases, the regulatory controls on fuelwood gathering from the natural forest must be enforced.

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Chapter 9

Forestry Technologies for Disturbed Forests

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Chapter 9

Forestry Technologies for Disturbed Forests

HIGHLIGHTS

Management of Secondary Forests

- About 400 million hectares (ha) of potentially productive closed secondary forests exist in tropical nations. If managed properly, secondary forests could satisfy the growing wood needs in the tropical nations that have substantial closed forests.
- Technologies to manage secondary forests are not yet adequate to assure suitable returns on investment. Technologies are needed to reduce costs and increase yields.

Reforestation of Degraded Lands

- Approximately 2 billion ha of tropical lands are in various stages of degradation. Opportunities exist to increase productivity of these extensive areas and, at the same time, meet the growing need for forest products and environmental services.
- Plantation management, like secondary forest management, is constrained by a lack of investment. Again, the solution seems to lie in reducing costs and increasing benefits.

INTRODUCTION

Growing populations and increasing needs for fuel, food, fodder, building materials, and work opportunities have caused selective logging and tropical deforestation. When cleared forest land cannot sustain the new land use, the consequences include land degradation, abandonment, and varying degrees of recovery. After either logging or agricultural clearing, the type of vegetation that returns generally depends on the intensity of land use and degree of degradation that have occurred and on whether the site has been grazed or burned. Usually, second growth forests appear; sometimes grasses invade, sometimes only barren wasteland is left.

The selection and application of forestry technologies on these lands will vary depending on the vegetation. If enough valuable trees exist in the secondary forest and the site is not too degraded, some form of canopy or understory manipulation can be applied. If the site is severely degraded and natural tree regeneration is difficult, complete clearing followed by site preparation and field planting may be more appropriate. The following describes various forestry technology options according to vegetative cover.

MANAGEMENT OF SECONDARY FORESTS

Background

Where tropical forests have been exploited by wood harvesting and/or by shifting cultivation, the land is commonly "returned to nature" and secondary forests are allowed to develop. Secondary forests, for the purpose of this report, include both residual forest that has been cut once or several times during the past 60 to 80 years and second growth forests that invade after periodic cultivation. This includes the "logged" and "forest fallow" categories discussed in chapter 3.

In the past, foresters considered tropical secondary forest trees of little use because the trees were perceived as having poor form, being inferior species, or simply too small. Most of these trees are not used except as poles or fuel. Unless an especially good market for fiber or fuelwood exists, secondary forest land usually is left idle or converted to marginal croplands.

These reasons for not investing in secondary forest management technologies are being dispelled as knowledge of secondary forest species improves. Secondary forests often are more homogeneous than mature forests because the vegetation that grows after a site has been cleared usually is dominated by a few pioneer tree species. This can simplify management, harvest, and use of the secondary forest. Furthermore, pioneer tree species are fast-growing, their wood is uniform and light, and their stems tend to be straight and dominated by a single leading shoot. Such characteristics can make these species marketable. Since the leaves of these species usually are large and thin, adequate light can reach the understory to permit development of dense undergrowth. This understory frequently includes late successional hardwood species that are valuable for timber—e.g., *Meliaceae.* Finally, the wood of the secondary pioneer species usually lacks resins and silica and this facilitates wood processing, although it makes the trees vulnerable to damage (19).

Technologies

Description

There are several technologies that could be used to improve the productivity of secondary forests. These technologies vary in intensity of treatment. The choice depends on the quality and quantity of tree species found in the forests as well as the management objectives. The following technologies are presented from least to most intensive:

- *No Treatment*—No silvicultural treatment is applied. The success of regrowth is dictated by the duration and severity of past forest modifications and by soil quality, moisture availability, and access to the area by missing components of the former forest, including tree seeds and animal life.
- *Refining*—This is also known as improvement felling and timber stand improvement. Some trees are removed to give more growing space to other, more desirable trees. The underlying premise is that potentially valuable trees, unless tended, will be constrained by competition with less valuable trees for light, moisture, or nutrients. It is justified only in forest stands that already contain enough valuable trees to promise an economic crop.
- *Tropical shelterwood*—This treatment consists of removing the upper layer of canopy in one or more cuttings to promote either germination or the growth of existing understory seedlings or saplings. Periodic weeding is necessary.
- *Underplanting*—Trees are planted under some living portion of the former forest to ensure a rapid-growing new crop of acceptable tree species.

Assessment

Each of these secondary forest management technologies has certain technical, environmental, economic, and sociopolitical constraints.

No Treatment.—Untreated secondary forests are low-input/low-output. The attractiveness of no treatment, with its lack of initial expense and investment, is offset by low harvestable yields (61). For instance, a 20-year record from unmanaged residual forests in Puerto Rico showed an annual yield less than 5 cubic meters per hectare (m^3/ha) (5). This calculation is based on merchantable timber. Thus, yields might be increased by expanding the market for the materials produced.

Repeated harvesting may cause an eventual decline in site productivity due to nutrient losses. Harvesting all the stemwood from a moist tropical forest can remove 10 percent of the ecosystem's nitrogen, 39 percent of the phosphorus, 38 percent of the potassium, 20 percent of the calcium, and 57 percent of the magnesium (20). However, development of harvesting systems that leave forest structure* and its nutrient-cycling mechanisms intact is constrained by financial considerations. For instance, although small-scale clearings recover more quickly than large disturbed areas, this approach often is not suitable for commercial forestry because of higher costs incurred in the transportation of labor and machinery.

Nevertheless, harvesting systems are being designed to reduce nutrient loss. A harvesting method used with some success in the United States has been proposed for adaptation to the Amazon forests (34). In this scheme, a strip of forest is harvested on the contour of a slope. A haulage road is built along the upper edge of the strip. After harvesting, the area is left alone until saplings appear. Then a second strip is cut above the road. Nutrients washed downslope from the freshly cut second strip can be captured and used by the new trees in the original strip. The remaining mature forest can provide seeds for regeneration. Once a network of roots is reestablished in a strip, another strip farther up the slope can be cut, the timber used, and the newly cut strip then regenerates naturally (fig. 27).

Strip logging, like clear-cutting, has economic problems because many of the tree species cut do not have well-developed markets.

Refining.—Forest refinement has advantages and disadvantages. Few good trees are needed for this treatment. As few as 100 saplings per hectare, if refined, could produce a fully stocked crop of mature trees (11). But logging damage and post-logging mortality can limit the use of this treatment (49,55). The application of logging controls throughout the Tropics might greatly increase the area of forest meriting refinement. For instance, successful control of logging damage in the Philippines has enabled the use of refining in large areas (22).

Refined moist secondary forest produces about 6 m^3/ha/yr of merchantable wood (14), a quantity similar to that from untreated forest. There is an improvement, however, in wood quality. Results vary widely with forest stand history. Although yields are low relative to those of more intensive management technologies, the required investments are also low and often in line with available financial resources (38,51). Thinnings seem to shorten the time between harvests (31). Also, when the full costs of more intensive technologies are taken into account, refining may compare favorably with the intensive treatments (38). Nevertheless, more research data are needed, especially about costs and financial returns, for complete analysis of this treatment.

A variation of the refining practice is known as "*liberation thinning*." In this technique, desired trees are identified and liberated from competition with less desired tree species. It is an important element in the silviculture of residual *Dipterocarp* stands in Sarawak (31). However, in general, only large clearings are needed to stimulate understory growth, and sometimes even these fail (12). The selected trees, if subordinate in canopy position in early life, may be incapable of later accelerated growth.

Another variant of the refining practice is the *polycyclic system* (or selection silvicultural

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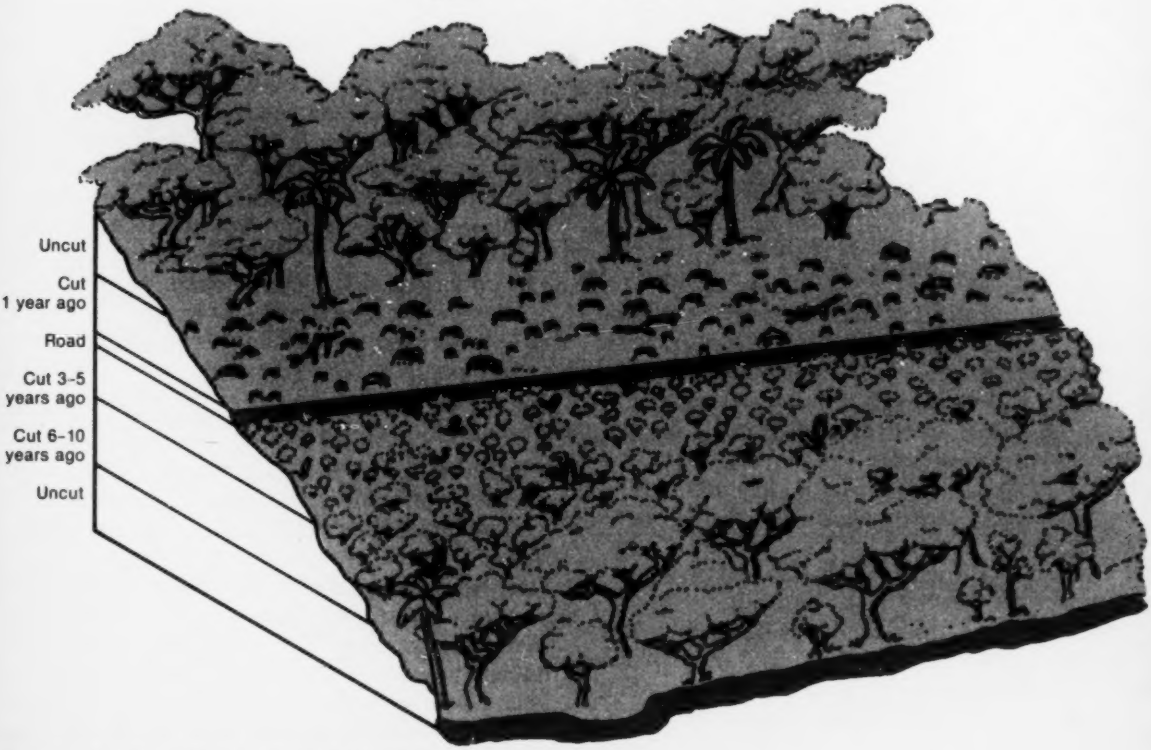
*Forest structure: distribution and arrangement of trees in a forest stand.

Figure 27.—Harvesting Scheme



SOURCE: C. F. Jordan, "Amazon Rain Forests," *American Scientist* 70(4): 394-401, 1982.

system), which preserves the natural forest structure. Mature trees are harvested periodically, thus liberating immature trees. It has been successful in some *Dipterocarp* forests of the Far East because those forests are dominated by a single type of tree and natural regeneration of that type usually occurs (41). Sometimes all the high-quality tree species are extracted, thereby leaving behind a commercially useless forest. Also, the widespread use of girth limits for determining maturity means that the most vigorous, rapid-growing trees are removed, leaving behind what could be poorer seed-bearers.

The criticisms of the polycyclic system should not, however, preclude its future use. Markets are developing for trees with smaller crowns, and felling these should do less damage to surrounding trees. The growing local marketability of many additional species should increase the feasibility of more complete fellings.

Yet another variant of the refining practice is the *monocyclic system*. The objective is to have all trees reach maturity simultaneously for a single harvest. It starts with the removal of all undesired species down to 10 cm in diameter at breast height (15). Drawbacks to this treatment are the initial sacrifice of larger trees and a lack of intermediate harvests for added income. Moreover, monocyclic management leads ultimately to more complete harvests with greater prospects for erosion. Heavy cuts from monocyclic management can be expected to lead to periodic interruption of nutrient recycling, since large volumes of logging slash will be decomposing at a time when an effective network of roots to capture the nutrients is lacking.

Refinement directly reduces an ecosystem's diversity, gradually eliminating as many as half of the tree species, especially those small at maturity or with extremely light or heavy woods. It calls for ranking species in order of desirability. Consequently, criteria must be determined for selection that consider not only marketability but also the capacity of the system to capture and conserve energy and nutrients, and the risks of catastrophic damage following reduction of biological diversity.

At present, the case for refining secondary forest can best be made where the need for soil, water, and wildlife conservation is critical and where soils are unsuited for other purposes. If carefully coordinated with land-use planning, forest refining may provide seasonal employment in farming regions.

Tropical Shelterwood.—This complex practice stimulates growth of existing seedlings and saplings chiefly by removing unwanted mature trees (58). It requires a reasonable number of existing seedlings, and a new seedling crop rarely appears unless there are at least 2 or 3 mother trees (7,10,27,40). A variation, the Malayan Uniform System, is applied chiefly in the lowland *Dipterocarp* forests of Peninsular Malaysia, where there are at least 2,500 seedlings of good species. It requires nearly complete removal of all trees except desirable species of less than 30 cm in diameter.

The practice, so far, is not profitable. Average expected timber yields are about the same as from refining, about 6 m^3/ha/yr. However, labor costs are higher because the treatment requires removal of the overstory and continuous weeding before harvest. It has been abandoned in Malaysia, Borneo, and India because of labor costs (23,32). Better techniques are needed to reduce treatment costs and improve economic returns. At present, tropical shelterwood is applicable only in places with low labor costs, extensive secondary forests, and little capital to invest in plantations (61).

In addition, this treatment may lead to loss of nutrients by leaching or erosion because the canopy is kept open for a number of years. If the technology were used for several rotations, there would be progressive simplification of the forest ecosystem.

Underplanting.—This practice is intermediate in intensity between natural regeneration and plantations. The objectives are the rehabilitation of cutover forests after selective felling of marketable trees and the assurance of full stocking, species control, crop uniformity, short rotations, and competitive yields (6).

There are several variations of underplanting. In forests containing most of the trees required for a future crop, individual trees are planted to fill small vacant areas. This is called "*enrichment*" planting. The main disadvantage is that uneven growth rates between the natural forest and the underplanted trees produce an uneven stand that is difficult to manage and harvest. "*Gap*" planting of trees spaced at 2 to 3 m inside openings of 20 m or more in diameter is another variation. It seems to have the same disadvantage as enrichment planting. "*Group*" planting is made up of closely spaced clusters of 9 to 25 trees in openings as small as 10 m in diameter. Only one tree per cluster is intended to survive.

In forest stands with an insufficient number of trees to form a significant portion of the next crop, underplanting may be done systematically in rows or lines. This provides more tree/site selectivity and requires less planting stock.

Line planting seems to be the successor to most of the other underplanting techniques; however, it also has problems (61). Not only must overhead shade be removed initially but weeding must be so drastic that most of the former forest quickly disappears (8). Clearing lines and keeping them open until the new trees are well established also can be expensive. Since most failures in the past have been a result of competition with natural trees, self-pruning tree species capable of 1.5 m/yr of straight growth are suitable (63). The list of marketable species that meet the growth requirements is limited. Also, line plantings typically are of a single species, producing a loss of stand diversity, even though natural regrowth may be permitted between and below the crowns of the planted trees. Finally, maximum yields to be expected from line plantings are about 12 m^3/ha/yr (13). The constraints may make line planting a risky investment.

Underplanting, however, is less costly and less intensive than plantations. It requires less planting stock and may rehabilitate poor sites and degraded forests. The problem of having a longer wait before harvest may be ameliorated where a planted understory can be harvested on a relatively short rotation for poles, fiber, or fuelwood.

Constraints and Opportunities

Existing secondary forests, if managed properly, could satisfy the wood needs of the growing populations in tropical nations for many decades. However, the various technologies for managing secondary forests are often complex, slow, and laborious. Yields are often too low relative to costs, which discourages investments. New technologies are needed to reduce management costs and to sustain and increase the yields of secondary forests.

An often appropriate technical approach to increasing yields is improved harvesting. Simply reducing logging damage can increase the number of trees available for a future crop as well as improve natural regeneration. This can be accomplished through the use of appropriate harvesting equipment. In addition, regulations to control logging practices need to be developed and enforced. Perfection of these practices requires additional research on the relationships between harvesting intensity and growth of the residual forest.

Another opportunity to increase yields and enhance the value of secondary forests is to develop markets for lesser-known tree species. Market development requires information on wood properties of lesser-used species, the further development of processing techniques, and juxtaposition of wood production areas, processing plants, and market outlets. Expanded markets would then justify more complete and efficient harvesting. Developing markets for underused species and size classes may do more to enhance the value of secondary forests than silvicultural improvement (61).

Finally, management of secondary forests may be made more attractive by reducing the cost of various silvicultural treatments. For example, survivorship and yield of planted trees can be increased by developing less expensive and better quality forest tree planting stock. Labor costs could be reduced by developing less expensive and longer-lasting methods of weed control.

REFORESTATION OF DEGRADED LANDS

Background

Tropical nations have about 650 million ha of cropland compared with 2 billion ha of land in various stages of degradation (21,59). Degradation of tropical land is a physical, chemical, and biological process set in motion by activities that reduce the land's inherent productivity. This process includes accelerated erosion, leaching, soil compaction, decreased soil fertility, diminished natural plant regeneration, disrupted hydrological cycle, and possible salinization, waterlogging, flooding, or increased drought risk, as well as the establishment of undesirable weedy plants. There is a strong relationship between inappropriate land-use practices and land degradation. In some places, degradation is manifest (e.g., desertification), where in others it is inferred (e.g., declining crop yields).

Deforestation in mountainous regions is one of the most acute and serious ecological problems today (17). Disturbance of vegetative cover on montane areas with thin soil and steep slopes results in land instability (e.g., land slides) and soil erosion. Excessive erosion not only impairs site productivity but may also adversely affect other sites or water bodies farther down the watershed. No precise estimates of the scale of the problem exist. However, data from the Food and Agriculture Organization (FAO) and other agencies indicate that some 87 million ha of tropical montane watershed land need reforestation (63).

Conversion of tropical moist forest into farm or grazing land commonly results in rapid depletion of the soil's plant nutrient supply and accelerated soil erosion. In some places the degradation process leads to takeover by persistent, aggressive weed species of low nutritive value (3). Often the combined problems of low soil fertility and weed infestation become so great that the land is abandoned. Such lands are subject to frequent uncontrolled fires and are often covered by coarse grasses. Whenever the vegetation is burned, erosion may increase and productivity may be reduced further. The extent of these grasslands is not well documented. *Imperata,* the main invader grass in Southeast Asia and part of Africa, occupies some 16 million once-forested hectares in Indonesia (36). If the percent coverage of the rest of Southeast Asia is similar to that of Indonesia, there may be 40 million ha of *Imperata* grasslands in the region.

In many arid and semiarid open woodlands, overgrazing and repeated fires have converted the vegetation to a degraded fire climax stage. Consequently, soils become dry and little woody plant regeneration occurs. Fire-tolerant vegetation—commonly unpalatable to animals—persists, leading to a desert-like state. An estimated 20.5 million ha of tropical arid lands, an area about the size of South Dakota, become desertified every year. To date, an estimated 1.56 billion ha of tropical land have undergone human-caused desertification (63).

Each year, approximately 500,000 ha of excessively irrigated lands become saline or alkaline as a result of inadequate drainage or use of salty irrigation water (63). Capillary action draws moisture to the soil surface where it evaporates, leaving salts in or on the topsoil. In some cases, salts can be leached from upland soils and bedrock, raising the salinity of runoff from deforested slopes. The increased runoff harms agricultural soil in lowland areas by causing temporary or lasting waterlogging and salinization (4).

The best solution to such problems is to prevent inappropriate land-use practices on forested lands. Where it is too late for this approach, reforestation is an alternative. Trees planted on degraded lands will not give such high yields as trees planted on rich, fertile lands. However, it may be the only way to raise the productivity of the most degraded lands. Furthermore, in many countries, fertile sites are reserved for agricultural activities. Given the dwindling reserves of good land and the increasing amount of degraded tropical lands, reforestation is a technology with potential to rehabilitate soils and to provide many goods and services for industrial and local needs. For example, fuelwood plantations can alleviate the worsening shortage of firewood in some areas and prevent shortages from occurring in others.

Technologies

An OTA background paper, *Reforestation of Degraded Lands,* covers this subject in detail. This section summarizes the mechanics of reforestation and focuses on pertinent issues and problems that may prevent reforestation success.

Land Preparation

Many degraded sites need some type of preplanting preparation, such as clearing stumps and competing weedy vegetation, loosening the soil, or applying fertilizers or lime. Under some circumstances, site cultivation controls weeds and improves soil aeration, soil biochemical activity, percolation of water, pH regulation, nutrient application, and surface evenness. The degree and type of land preparation depends on several factors: site and soil conditions, vegetative cover, species to be planted, and available capital and labor.

Land preparation can be done by hand or by machine. Manual methods are less constrained by the rainy season, they require few skills, and the capital cost is relatively low. They also provide temporary employment to laborers and cause minimal damage to soil. A disadvantage of manual clearing, however, is the need to recruit, manage, and provide logistical support in remote areas for large numbers of laborers. Mechanical clearing, on the other hand, requires high capital inputs for equipment maintenance, supplies of fuel and spare parts, and operator training and supervision. And heavy machines degrade the site through topsoil disruption. Yet, in general, mechanical clearing is cheaper than manual clearing (18). The choice between manual and mechanical land preparation must be made on a case-by-case basis, determined by all these considerations.

Sometimes physical structures must be built and heavy machinery must be used to prepare sites. Artificial barriers of brushwood or other materials constructed in a grid pattern, or grasses and trees planted in a similar pattern, can be used to immobilize drifting sand. Plowing the soil surface to increase water infiltration, ripping across the slope to retain water, plus construction of bench terraces on steeper slopes, and funneling moisture onto a smaller area are all conservation measures used to maximize planting success. Minicatchments built to concentrate water into the rooting zones of individual trees are a particularly important technique in arid zones.

It may be necessary to add nutrients during land preparation. Several techniques exist including mulching with organic matter, planting nitrogen-fixing trees, applying green manure (especially herbaceous legumes), and commercial fertilizers. Mulching suppresses weeds, improves soil moisture conditions, and augments soil organic matter (53), but it may increase problems with rodents or other pests. Nitrogen-fixing trees can improve soil with their ability to produce nitrogen fertilizer. Foliage dropped by legumes is nitrogen-rich and will augment soil fertility as it decays.

Historically, tropical foresters have relied more on seed provenances and thinning practices than on commercial fertilizers to increase productivity (52). But the benefits of fertilizers have been impressive in some forest plantations. Fertilizer placed in the planting hole may accelerate early height growth and thus reduce weeding. Carton de Colombia, a timber growing company in Colombia, has experimented successfully with the application of about 50 g of commercial fertilizer in planting holes on extremely nutrient-poor soils (39). Since small amounts of fertilizer can produce significant results, further research is justified to determine the best types and quantities of nutrients to apply for various species under various soil conditions.

The use of commercial fertilizers in forestry generally has been based on a presumed or predicted shortage of nitrogen, phosphorus and potassium. Dosage has been based on experience from trial and error experiments. However, some highly weathered tropical soils are difficult to fertilize effectively with essential plant nutrients such as phosphorus and potassium. For instance, phosphorus can become so tightly held by soil minerals that plants can extract little for their benefit, whereas potassium is not held by the soil and is easily leached away by tropical rains (24,37). Use of the wrong fertilizer, or incorrect amounts of fertilizer, can reduce yields. Application of 100 g of potassium chloride per *Pinus caribaea* tree depressed growth and increased mortality on Nigerian savanna sites (35). Moreover, fertilizer use may cause water-associated environmental problems, such as increased eutrophication that hampers navigation (29) and may trigger the onset of health problems. Thus, fertilizers can be both beneficial and detrimental, so the impacts of applications need to be examined thoroughly before widespread use.

Some experts adamantly believe commercial fertilizers should not be promoted for the developing world on the grounds that they must be imported and are not, or soon will not be, affordable. Certainly, sustainable nonchemiical techniques to enhance fertility should be investigated. For example, one of the less obvious soil deficiencies, occurring particularly in eroded soils in the drier climates, is the lack of necessary micro-organisms. An ancient and effective method to add micro-organisms is to inoculate either nursery soils or planting holes in the field with a few grams of topsoil from well-established plantations. The method is not practical, however, where well-established plantations do not exist.

It seems unlikely that timber crops can be harvested repeatedly from the same site without replenishing soil nutrients. Significant decline from successive timber crops has not yet been observed (16,42,44). The quantities of nutrients removed with tree harvests have been measured, however, and they are sufficient to suggest that with repetitive cropping a decline in yield eventually will occur. Nutrient drain can be more rapid in fuelwood plantations where the cutting cycle is every 5 to 10 years in contrast to commercial forests that are cut every 30 to 100 years. This difference is even greater than the time difference implies, since younger trees contain a proportionally larger share of phosphorus, potash, and calcium (56). Nutrient levels and fluxes in plantations should be monitored to determine the prospective benefits and cost effectiveness of soil amendments.

Species Selection

Tree species selection is important to plantation success. If a tree is grown under unsuitable soil or site conditions, it will be stressed and thus become susceptible to attacks from insects or competition from weeds. Several factors influence species selection, including the objectives of reforestation, seed availability, and costs associated with reforestation alternatives. For many degraded sites, the species need to be those that can add nitrogen to the soil as well as provide products wanted by local communities.

The importance of matching tree species with site cannot be overstated. The problem of species selection is complicated in the Tropics by intricate climatic and soil patterns, and in areas that have been deforested by the highly variable degree of site degradation. Inadequate information on planting sites is a major cause of plantation failure (61).

Exotics and Monocultures. Plantations cannot substitute wholly for natural forests as reservoirs of germ plasm or as components of the natural environment—they are really an agricultural crop. Plantations contribute to preservation of the natural environment because they concentrate wood, food, and forage production within a minimum area, thus relieving some demands on natural forests. However, where plantations are established on land with good potential for annual agricultural crops, the effect actually may be to increase pressure on the natural forests.

Most large-scale tropical industrial timber plantations use species that are indigenous to the Tropics but are exotic to the planted area (24). The widespread use of exotics may be a result of the preponderance of information, experience, and research on them, especially on *Pinus, Eucalyptus,* and *Tectona.* Also important to their use is the abundance, availability, ease of storage, and germination of seeds of these exotic species. The use of exotic tree species involves risks. One of these risks is the susceptibility to pests and diseases. Proponents point out that exotics may be at an advantage because they have left behind pests and diseases that evolved along with them in their native habitats. Opponents disagree, saying that exotics may have no resistance to pests and diseases in their new environment. A third side believes that the risk of pest and disease problems depends on plantation size more than geographic origin of species. Native pests and diseases tend to switch to plantation crops (where resources are more uniform and abundant) (57). The evidence still is inconclusive. Because of the high yields possible with exotic species, however, the risks will continue to be taken.

The potential of using native species in plantations has been largely ignored. Reasons for this vary from lack of familiarity with many tropical tree species to lack of seed supplies. A reason often cited is the slower growth of native species. Nevertheless, the growth rates of exotics and native species usually are similar in the arid and semiarid parts of Africa (62). Native species are adapted to the local environment and, thus, may be less susceptible to stress, serious disease, and pest damage. Local people are more familiar with their native plants and have more uses for them (30).

Nearly all tropical plantations are grown in monoculture.* The main reason is that silviculture** for such plantations is simple and thus more cost effective. Since monoculture plantations may be susceptible to rapid spread of pest and disease outbreaks, some diversity can be achieved by alternating species, or genetic varieties of the same species, in blocks of land being planted. This method might prevent pests that develop and multiply in one plantation block from spreading rapidly to other blocks having the same genetic makeup (64).

Multiple species (polyculture) plantations, in theory, mimic the natural forest, yield a greater variety of products, and are less susceptible to pests than are monocultures. However, little actual experience has been gained dealing with polyculture plantations either on an industrial scale or in village forests (63). Only recently have projects been established where mixtures of species are planted for a variety of end uses. Legume trees are interplanted with commercial tree species to reduce the amount of fertilizer required after successive rotations. In experimental plantations, Indonesians are interplanting *Calliandra* with *Pinus merkussi* and with *Eucalyptus deglupta* to yield firewood for local use. *Calliandra* and other legume trees are sometimes used as "nurse trees" for timber such as teak, which requires shade initially for better growth (46).

Photo credit: J. Bauer

In the Caribbean National forest, Kadam (*Anthocephalus chinensis*) is intercropped with mahogany (*Swietenia macrophylla*)

Managing mixtures of tree species for wood production is biologically complex, especially for more than two species. It becomes even more difficult where multiple products are extracted from multiple species under different harvesting regimes. Information is lacking on the optimum species mixtures and spacings. Little is known about the relative benefits of different species or canopy densities and whether the density that is best for high yields is also satisfactory from other standpoints. Potential benefits from compatible mixtures of trees suggest that new concepts and combinations should be tested.

Forest plantations in the past usually served industrial purposes and grew only one product, usually sawtimber, pulpwood, or fuelwood. Now, with an increasing demand for food, fuel, and fodder, plantations are needed to serve a wider variety of objectives. Thus, the use of multipurpose trees is becoming increasingly important, especially in areas with high populations. For example, *Acacia mangium,* which has potential for sawtimber, veneer, furniture, firewood, pulp, and particle board, outperforms other species on degraded lands in Malaysia. Its leaves also can be used as forage for livestock (48). The foliage of species such as *Calliandra* is readily eaten by cattle and goats and its flower provides rich nectar to produce honey (47). Because of its fast growth, *Calliandra* competes with and can eventually suppress *Imperata cylindrica,* a tough perennial grass that invades and dominates many cutover areas of Southeast Asia.

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*Monoculture: one species planted over a large area.

**Silviculture: the science and art of cultivating forest crops, based on a knowledge of forest tree characteristics.

Thousands of other tropical trees exist whose potentials are unknown. Little is known of the variability in growth and performance of multipurpose tree species. Variation is related to habitat so that each planting site should be tested with a variety of species and with genetically different varieties of the same species. Even when correct species and provenances are known, there is still a major gap in the knowledge of silvicultural techniques for multipurpose tree plantings.

Tree Selection and Breeding. Since most tree species used in reforestation are found over broad geographic ranges, different races* within the same species can be adapted to different environments. Thus, the species' suitability to a particular site varies depending on the races used. Increases in yield and resistances to disease can be achieved through selection and use of appropriate seeds. Only by planting species and races on the sites for which they are adapted can maximum yields be obtained. Most plantations in the Tropics use seeds without testing them to see whether they are genetically appropriate for the site.

Selection of tree species for each site continues to be too arbitrary in spite of, or possibly because of, long experience and tradition. Plantation yields within large regions with extensive plantations of the same tree species, such as southern Brazil, vary widely from place to place with no technical explanation. Even large, long-established planting projects continually encounter new sites where results are unlike those of past plantings. Within genera such as *Eucalyptus,* selection among species and races should be made on the basis of natural range and corresponding climate and soil conditions for which each has proven acclimatized, and on the basis of demonstrated adaptability to altered environments and growth habits (9).

A well-established technique to match races with sites is called provenance testing.* Seeds of the desired species are collected from various sites and tested at the site to be reforested or at a site with a similar environment. Once the best provenance has been identified, several options are available to obtain planting materials. Seeds from the desired provenance sometimes can be purchased. Alternatively, individual trees from the provenance test can be selected as parent material and used to establish seed orchards or to produce rooted cuttings for planting materials.

Another technique is to use superior trees from an environment similar to the reforestation site to establish a seed orchard without provenance testing. If the desired species already grows on the reforestation site and if superior trees have not been eliminated, it is possible to obtain planting materials adapted to the site from those trees. This is probably the fastest and least expensive approach. However, seed orchards established from phenotypically** selected trees ideally should be provenance-tested.

Conventional provenance testing is a major undertaking. For proper statistical analysis, hundreds of trees from each seed source are planted in replicated blocks and grown to maturity. The process generally takes so long that the original seed source may be unavailable by the time results are available. When that happens, the test plots must be developed as seed orchards, further prolonging the process. This usually takes too long for an individual reforestation program to accommodate. Many provenance tests do not yield results because of premature termination of the project or departure of the investigator. Therefore, provenance testing must be carried out by established institutions that can maintain long-term programs.

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*Race: subdivision of a species distinguished by heritable physiological or morphological charcteristics resulting from adaptation to a specific environmental condition. Tree species races are often described by referring to the geographic location where the race is found naturally.

*Provenance testing: testing populations of the same species to study their performance under a range of site and climatic conditions.

**Phenotype: detectable expression of the interaction between the tree's genetic characteristics and the environment.

Potential to shorten the time needed for tree selection is increasing as new techniques are tested. Tissue culture can rapidly mass-produce clones of chosen individuals from a provenance test. The clones can then be tested for particular microsites or planted at the reforestation site. Establishment of international networks of cooperating scientists to collect seeds or planting material and to record environmental data for each parent tree can reduce the number of provenances to be evaluated for each test. Another technique, by which many provenances are planted in one stand (single tree randomized plots), allows the testing of many more provenances without a corresponding increase in budget or personnel. Then, propagation of clones can ensure that the provenance with the exact genetic materials is used, thus allowing more types to be tested. The U.S. Forest Service, in experiments with *Eucalyptus,* successfully used single tree randomized plots and cloning to shorten the time for screening provenances.

After the initial selection of parent trees, breeding for desired characteristics can greatly accelerate tree yields and survivability on degraded sites. Plant breeding has been responsible for about half of the spectacular gains in agricultural crop yields accomplished in the past three decades. Tree breeding takes longer because generations are longer than with annual agricultural crops. Nevertheless, tree breeding programs in industrialized nations have already achieved important productivity gains—10 to 20 percent gains in first generation and 35 to 45 percent in second generation seed orchard progeny in industrial timber plantations (50). For energy plantations, breeding has produced gains of as much as 50 percent (54).

With *Eucalyptus* in Brazil, selection alone has nearly doubled yields (60). Additional gains from the use of parent trees selected by strict criteria are predicted at 5 to 10 percent and the use of seed orchards of these trees should add 10 to 20 percent more. Tests to match the seed orchard progeny to specific microsites are expected to provide further gains of 35 to 45 percent. Eucalyptus breeding has produced hybrids that at 4 years show an improvement of 30 percent in height growth and 80 percent in diameter at breast height (dbh) growth over the parent trees. Yields of more than 100 m^3/ha/yr are projected from the combination of selection and breeding. Hence, genetic tree improvement may promise larger gains in yields than refinement of silviculture techniques.

In addition, tree selection and breeding could accelerate genetic improvement of trees for characteristics other than yield. For example, with pines, improvements similar to the eucalyptus yield gains are expected in straightness, reduction in forking, and other characteristics. Further, the risks of forestry investments on degraded land could be reduced. For example, drought-resistant species could be improved through genetic programs designed to identify, breed, and propagate the most productive of the drought-tolerant provenances.

Planting Materials

To reforest lands, seeds of various species must be available in great quantities. Today, quantity falls short of need. The seed supply for species most commonly used in tropical, industrial plantations is adequate. However, the seed supply for multipurpose, agroforestry species is small. Often the seed that is used does not have its source identified. This makes it impossible to trace the origin of seeds that produced a promising stand or a stand of bad form to be avoided. Full records of all forest seedlots should be made and copies should accompany all seed distributions. Most importantly, every seed shipment should show how the species was identified, where and when the seed was collected, and specific site and stand information about the seed source. In that way, the recipient would know the quality and origin of a seedlot if problems or opportunities were to develop later.

The customary way of raising planting stock in the Tropics is to grow seedlings in a forest nursery either in open beds for bare-root planting or in containers. Good nursery practices are essential to produce a hardy plant with a well-balanced, straight root system. Bare-

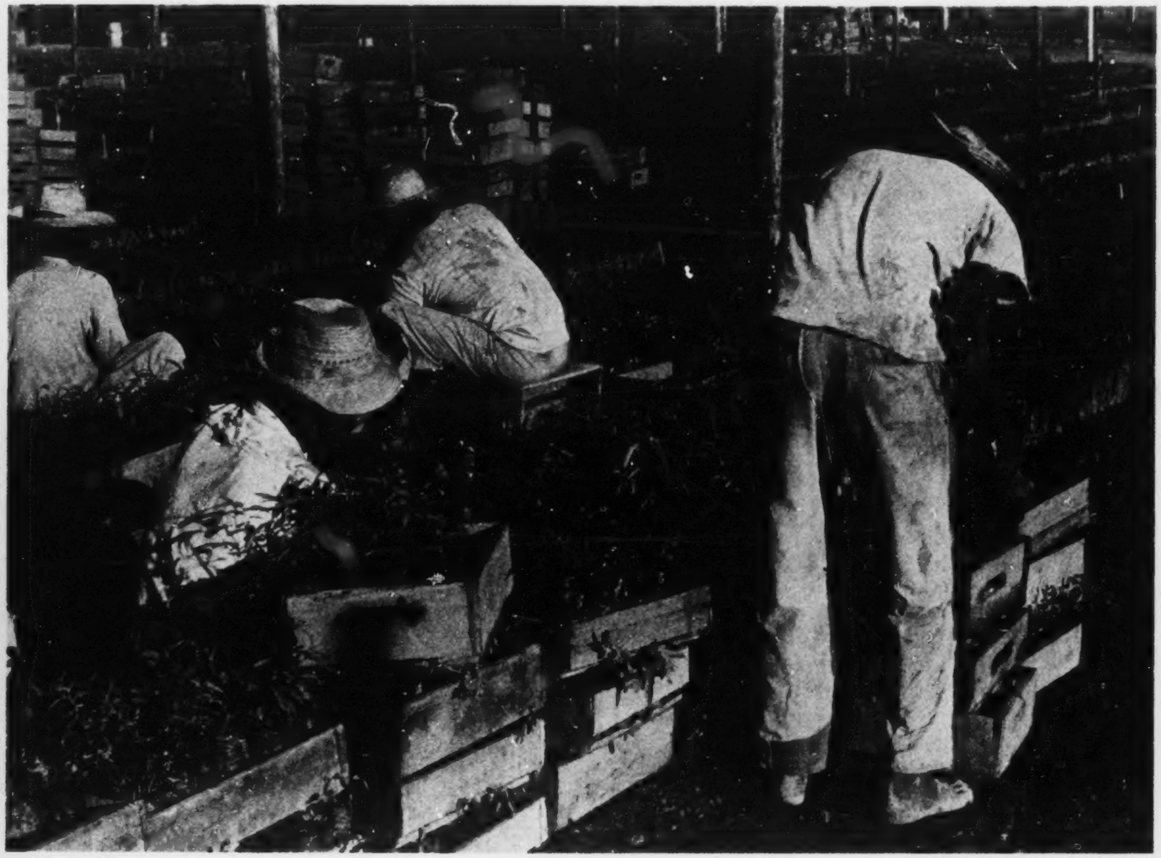

Photo credit: A. Isaza for WFP/FAO

These 200,000 *Eucalyptus* seedlings will be used to reforest some 700 hectares of overgrazed land in Colombia

rooted seedlings are susceptible to desiccation. Containerized seedlings are more costly and bulky to handle in the field and are subject to root coiling if closed-bottom containers are used. The latter can be avoided if the containers have an open bottom and are suspended above the ground. Recent developments with cardboards and plastic tubes used as seedling containers are increasing the efficiency of reforestation projects.

Another technique for producing planting material is vegetative propagation—reproduction of planting stock without the use of seed. Vegetative propagation is widely used for tree crops such as rubber, coconut, tea, coffee, cocoa, and oil palm. Methods include cuttings, air layering, budding, grafting, and tissue culture. Rooted cuttings remain the most popular of these. Once the technique for a particular species is developed, the production cost is modest.

Vegetative propagation has the advantage of hastening massive reproduction of genetically superior plants, ensuring that all are of the desired genetic type. It has the disadvantage of increasing plantation risks due to lack of genetic diversity. Tissue culture is another technique that can produce thousands or even millions of plants rapidly from a single parent. This technology is established in tropical agriculture and horticulture, but it is still in the developmental stage for most tree species.

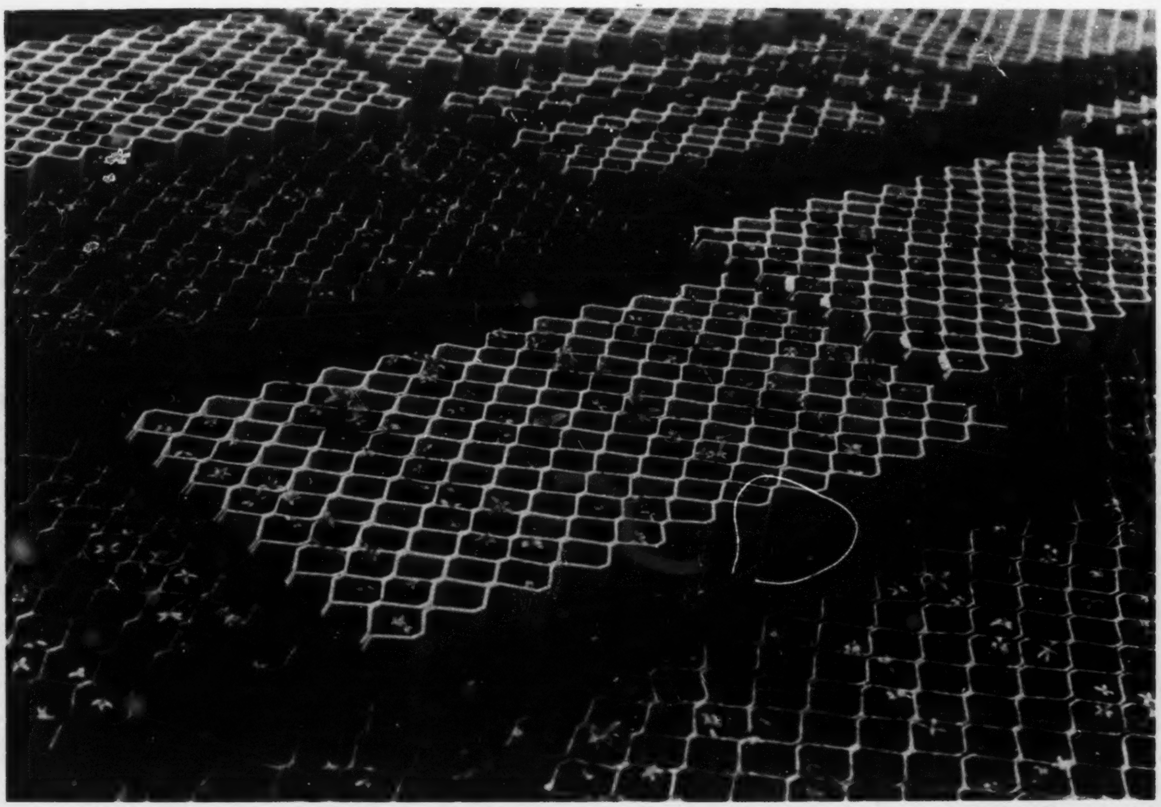

Photo credit: K. Parker

Development of tree seedling containers such as these win-tubes at Operation Double Harvest nursery in Haiti has improved seedling survivorship

The use of tissue culture can shorten the time necessary to reproduce a large stock of planting material with exactly the necessary characteristics. The cost of plantlets and the sophistication of the technique, however, make it unlikely to replace the use of cuttings for large-scale reforestation in tropical areas. Its nearer-term use is likely to be in establishing "supertree" orchards to produce seeds or cuttings.

Seedling survival and growth rates in the nursery and at the planting site sometimes can be improved by using special kinds of fungi and bacteria. For most tropical trees, associations between tree roots and mycorrhizal fungi are essential for healthy growth. The fungi are active in the transport of nutrients and water to plant roots, and in some cases are important for the release of nutrient elements from mineral and organic soil particles (43). Trials have shown that seedlings inoculated with fungi show improved growth and survival over uninoculated controls (33). Populations of mycorrhizae are found naturally in soils, but these can be depressed after long-term clearing and/or topsoil removal, making reestablishment of vegetation on degraded lands difficult. Various methods for reinoculating damaged soils with mycorrhizal fungi are being developed.

Legume trees can grow well on degraded land because their roots can be a symbiotic host for *Rhizobium* bacteria which produce nitrogen fertilizer, an essential nutrient for plant growth. The bacteria convert nitrogen gas in the soil into a form the plant can use. Most soils contain *Rhizobium*, but degraded soils prob-

Photo credit: T. Wood

Nitrogen-fixing nodules formed on the roots of *Acacia Pennatula* by *Rhizobium* bacteria enable legume trees to grow well on degraded lands

ably contain fewer types and lesser amounts of the bacteria. Thus, the appropriate type of *Rhizobium* may not be present at the site of a reforestation effort, or present in enough quantity to infect the tree roots.

Inoculants are living organisms that must be transported and stored carefully and used correctly to retain their viability. These requirements can be difficult to satisfy, especially at remote tropical sites needing reforestation. Most importantly, inoculants for tropical legume trees usually are not available because of lack of production. Even where inoculants are available, they may not be used because treeplanters are not convinced that they will be helped. These constraints are being overcome slowly.

An old inoculation technique is to collect root nodules from a vigorous legume tree, grind them up, and use the product to inoculate other trees of the same species. The newer technologies using inoculants from laboratory produced cultures are relatively simple to use and cheap, costing only a small fraction of a cent per tree. Inoculation of legumes with *Rhizobium* has been practiced in agriculture in industrialized nations for many years. Inoculants for some tropical legume trees, such as *Leucaena* and *Calliandra,* are available commercially.

The roots of some nonlegume trees also can be infected by micro-organisms that produce nitrogen fertilizer for the tree. Techniques to culture these micro-organisms are not yet available. However, the use of ground-up nodules from already established trees is possible and practical for areas where these trees are native. The major limiting plant nutrient in arid and semiarid regions is likely to be nitrogen; hence, the use of nitrogen-fixing trees can be extremely valuable.

An alternative to using seedlings in nurseries is to plant or sow the seed directly at the reforestation site. This method is feasible where seed is plentiful and where seed and seedlings mortality is low. Direct sowing of drought-resistant species is sometimes preferred, especially for species that have long and fast-growing taproots that may be damaged in a nursery or in transfer to the field. The advantage is that no nursery is required and planting costs are low. On the other hand, seedling survival may be low because of weed competition, lack of tending, poor weather, or animal damage.

Coating seeds with pest repellent may be necessary to avoid damage by small mammals, birds, or insects. Thus far, few species have been planted this way in the Tropics. Sowing seeds from the air is unproven in the Tropics, but shows promise in accelerating reforestation programs through its ability to seed large areas quickly (45). It is a tool to consider when reforesting remote, rugged sites. The technique has many logistical problems, including lack of aircraft and logistic, administrative, and communications support, and lack of large quantities of seeds.

Tree Care and Maintenance

Proper care and maintenance of the planted site is essential to ensure that trees survive to maturity. Once grown, there is the problem of monitoring timber harvests and of systematic replanting. The main causes of reforestation failure, other than inappropriate technologies, are uncontrolled grazing and fires, competition from weeds, and uncontrolled cutting for fuel, fodder, poles, and lumber.

Direct protection through fencing or guards tends to be expensive. Other, less costly methods include planting unpalatable trees (e.g., *Cassia samea*) or thorny trees (e.g., *Parkinsonia*) as barriers around the plantation. The use of living fences is becoming a more widespread practice because they provide a number of auxiliary benefits including shade, fodder, windbreak, fuel, and wildlife habitat. Another alternative is subsidizing farmers with livestock feed or with cash to purchase feed during the period when trees are most susceptible to animal damage. Grazing beneath the tree canopy sometimes can be beneficial as a means of weeding. However, livestock grazing on recently reforested watersheds can be harmful because animals compact the topsoil, leading to poor tree growth and increased runoff.

Weeding is an important aspect of plantation establishment and maintenance. Weeds compete directly with seedlings for light, soil nutrients, and water. Their shade can smother and eventually kill young trees. They also can increase fire hazards and shelter harmful animals (18). There are three main methods of weeding—manual, mechanical, and chemical. The manual method is the most common and requires little skill or capital. Mechanical methods may be used in large plantation projects but generally are not considered profitable in the Tropics. In many tropical countries, chemical weed control techniques have been tested and found successful, but because of safety and cost problems they seldom become the main means of weed control (1).

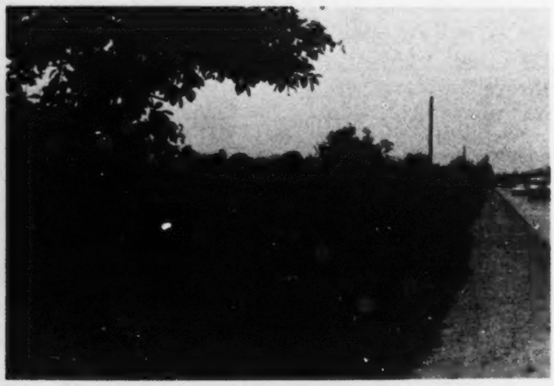

Photo credit: K. Parker

Using trees as living fence posts in the Dominican Republic has several benefits. The fence itself provides protection and shade for animals, while the foliage can be harvested for forage, fuelwood, or green manure

Whatever the type and location of tree planting, the cooperation of local people is essential if newly planted trees are to survive (2). Because most trees do not yield much benefit for several years, the options offered must demonstrate explicit benefits to the people. Tree planting programs are most successful when local communities are involved and when the people perceive clearly that success is in their self-interest.

In local communities, support can be generated through local involvement in project design, demonstration plantings, commercial plantings by entrepreneurs with larger land holdings, education of community leaders, extension and training programs working directly with farmers or laborers, and direct financial assistance or provision of substitutes (63). Village woodlots provide an alternative to cutting in larger areas reforested for other purposes. Subsidizing kerosene is also an option until wood can be harvested on a sustainable basis in reforested areas.

Incentives must be created to encourage people to care for and maintain the reforested area until the benefits can be reaped. For example, a village woodlot project in the State of Gujarat in India that involved tree planting on degraded communal grazing lands was able to meet people's needs by allowing grass to be cut for fodder and carried to livestock during the second year of tree growth. This approach enabled people to continue feeding their livestock and simultaneously to care for and maintain the reforested area (2).

Other incentives include guaranteed provision of inputs, credit, and technical assistance when required. Where land tenure is a problem, measures can be formulated to offset the risk to participants caused by the lack of secure ownership of the trees—e.g., giving title to the land or title to the trees, short-term licenses, or improved financial incentives.

Investment Analysis

Reforestation projects may fail to receive adequate funding and support because benefit/cost analyses do not include indirect benefits such as environmental services, import subsitution, and higher productivity of rural labor. Plantations have substantial technological requirements which, combined with the long-term nature of forestry, often result in low short-term profits when compared with those of alternative investments. This is often in conflict with government priorities for projects that produce quick returns (for which leaders receive more political credit) and with bankers who use discounting methods that assign low value to returns that occur 10 years or more in the future.

Adequate analysis requires comprehensive data on costs, benefits, and man- or machine-times and productivities. Yet much of this information is unknown when projects are being planned. Price estimates often are unreliable and do not account for inflation. Information on labor requirements is usually missing as well. Forestry yields are difficult to predict because of the long-term nature of the enterprise, climate and management uncertainty, and, more importantly, a lack of accurate information on site/species interactions. Although technologies such as tissue culture to accelerate vegetative propagation and bacterial inoculation to increase seedling survival are increasing yields on reforested degraded lands, methods are not yet developed to measure the important but indirect benefits that could help justify investment in reforestation.

Constraints and Opportunities

Reforestation technologies are available to be applied directly to degraded lands. However, forestry has low priority in many tropical countries. Tree planting sometimes does not compete well, in economic terms, with other land-use activities. The solution seems to lie in creating better economic terms by reducing the costs and increasing yields of plantations, by reducing plantation failures, and by developing methods to quantify indirect benefits of reforestation.

Overall costs could be reduced if land preparation were adequate to prevent weed invasion and ensure a favorable environment for the seedlings. The use of nitrogen-fixing tree species can add fertilizer to degraded soils. The use of native species may reduce the risk of disease and insect outbreaks and increase local enthusiasm for reforestation. Plantation yields can be increased through selecting high-yielding, fast-growing, soil-enriching, and stress-tolerant species and provenances. Multipurpose tree species can increase the diversity of products yielded. Development and implementation of tree selection and improvement programs can produce high-yielding varieties as well as other characteristics for particular tree species. Careful provenance testing, matching the appropriate race to a particular site, should improve species performance and reduce mortality. Perhaps most important is the proper maintenance of reforested sites. Incentives for local people should be created to minimize the incidences of fire, grazing, and fuelwood cutting.

Shortage of seeds is a major technical constraint to reforestation. No mechanism exists to control the quality of planting stock. It is often difficult to trace the origin of seed that does perform well to obtain more. Some mechanism needs to be developed to coordinate collection, certification, and international distribution of quality seeds in commercial quantities. This could be accomplished through 1) the

Photo credit: J. Bauer

Mahogany seed sun-drying for storage. Shortage of seeds is a major constraint to forestry. Implementation of programs to collect and disseminate seeds could increase reforestation efforts

creation of a new institution, 2) expansion of the FAO seed program, and/or 3) expansion of the seed banks of the CGIAR system to work with private tree seed production enterprises.

Oftentimes, inappropriate tree species are selected because information on optimum species and provenances for specific sites is unavailable. Much information on proven plantation establishment techniques and silvicultural data exists and some of it is being published. Yet, such information is seldom easily available to or studied by those who embark on planting projects. FAO could provide abstract/microfiche/hard copy services for published literature to operational and research personnel, especially at the field level; provide bibliographies, monographs, and manuals on relevant species, techniques, and systems; and provide incentives to publish local research and management techniques.

Furthermore, information on planting sites often is inadequate. The need exists for international coordination to disseminate what is already known about sites and species/site interactions so there is some uniformity of approach, at least at the regional level. Following this, there should be application of a comparable site classification to those areas most eligible for planting. There may be reason to establish two intensities of classification, one generic to narrow down the choice of prospectively adapted tree species, and one more specific to distinguish good, fair, and poor productivity within each broad class. Given the present large uncertainties in selecting the best method for reforestation of a degraded site, it may be advisable to try out several approaches (28).

Reducing the frequency of plantation failures may attract more investors to forestry and, thus, increase the extent of land reforested in the future. Also important are the indirect benefits from reforestation efforts. International development banks treat many of the nonmarket considerations qualitatively rather than trying to develop artificial values for them (25). However, simply listing nonquantified variables may serve to remove them from consideration. So increased effort must be expended to develop, test, and refine methods of quantifying indirect benefits so that decisionmakers have an understanding of the economic value of reforestation.

Successful reforestation requires sufficient funds, strong political will, massive popular support, and cooperation among all involved parties. A technical package, once accepted by funding institutions and the host-country government, may solve certain problems, but many obstacles to its acceptance usually remain. Foresters and policymakers must remember that "forestry is not, in essence, about trees. It is about people. It is only about trees so far as they serve the needs of the people" (26).

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Chapter 10

Forestry Technologies to Support Tropical Agriculture

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Chapter 10

Forestry Technologies to Support Tropical Agriculture

HIGHLIGHTS

- The medium- and long-term maintenance of tropical forest resources may depend more on sustaining lands under cultivation than on refining the use of the remaining forest.

Agroforestry

- Agroforestry, systems that use trees, crops, and/or animals on the same land, holds great promise for improving and sustaining the productivity of lands under cultivation.
- Genetic improvement of multipurpose tree species has great potential to increase the productivity of agroforestry systems.
- Rigid boundaries between disciplines have deterred agroforestry development. There is a need for a thorough rethinking of the appropriate institutional homes for agroforestry.
- Implementation of agroforestry systems relies on removing obstacles to adoption, improving extension services, and creating incentives to encourage farmers to adopt agroforestry practices.

Watershed Management

- Damage to tropical watersheds is most ecologically and economically significant where subsistence farmers and their livestock move onto steep uplands. Improved farming systems are needed that can ensure and enhance farmers' short-term returns and at the same time modulate water flow.
- Where flood protection for large populations in lower reaches of river valleys depends on protecting the vegetation on steep upper watersheds, costs for conservation practices in the uplands should be subsidized by the lowland communities.
- More research on the relationship between land use and hydrological systems is necessary to give watershed managers a better understanding of various management systems and their tradeoffs.

INTRODUCTION

The major cause of deforestation and forest degradation in most countries is land clearing for agriculture. In many places, the quality of land is degraded by conventional farming or grazing practices, so the farmers and herders must keep clearing more and more forest. This practice continues because people have no alternatives.

Many of the technologies discussed in this report can help to sustain forests by making forested land more productive and thus can help reduce the need for converting the land to nonsustainable uses. However, increasing the productivity of forests alone is unlikely to provide enough jobs or income for rapidly growing rural populations. For that, the productivity of agriculture has to be sustained and increased.

Agricultural productivity can be increased by enlarging the area farmed, maintaining the quality of the land already in use, and increasing the per hectare yields. Chapter 11 addresses planning technologies to direct land clearing onto sites that are appropriate for agriculture. This chapter addresses forestry-related technologies for the other two approaches. The objectives of these technologies are:

1. to enable farmers on marginal soils to continue farming in one location and to maintain or gradually increase land productivity so they can stop clearing more and more forest, and
2. to protect and allow improvement of agriculture in the more fertile river valleys by modulating waterflows and reducing erosion and siltation from upland watersheds.

AGROFORESTRY

Background

Traditional farming methods used in tropical countries were developed to reduce the risk of crop failures more than to provide maximum production. As a result, the traditional cropping and grazing systems used on relatively infertile, dry, or erosion-prone sites often involve multiple crops, intercropping, and complex crop rotation schedules. However, the traditional systems are not productive enough to provide for the rapidly expanding populations of the Tropics. They need to be modernized and further developed.

On fertile and well-watered alluvial soils where traditional farming was based on monocropping of rice or wheat, it has been possible to increase yields by adapting modern temperate-zone technologies, including applications of fertilizers and pesticides. But in the less well situated sites, many attempts to replace complex, traditional farming systems with modern monocrop agriculture have failed, apparently because of high risks from climate, pests, and difficult soils and because of the complex socioeconomic conditions that often prevail. So, in recent years, some scientists have begun developing modern technologies to improve, rather than replace, the traditional farming systems (26). This approach to tropical agriculture development is still promoted by only a small number of agricultural scientists.

Agroforestry is a name for a collection of land-use systems and technologies where woody perennials (trees, shrubs, palms, bamboos, etc.) are deliberately grown on the same land with agricultural crops and/or animals in either spatial arrangements or temporal sequences. Agroforestry is a new word, not a new concept. The novelty lies in formally recognizing that many different tree-based land-use systems possess certain common features that hold great promise in the Tropics.

On fertile lands, intensive agroforestry systems, like intensive agriculture, can support dense populations. Agroforestry, however, is probably more important for improving and sustaining the productivity of the lands with soil fertility and soil moisture problems, and where lack of rural infrastructure and cash make it necessary for people to produce most of their own basic needs for food, fodder, fuel, and shelter.

Agroforestry Systems

Description

Agroforestry encompasses many well-known and long-practiced land-use systems on cultivated or grazed lands in the Tropics (table 29). Traditional shifting cultivation, bush fallow systems, and all forms of "taungya" afforestation* fall under this term, as do the home gardens of the wet tropics and the use of fodder trees and shrubs in the dry Tropics.

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*Taungya: Burmese for hill cultivation. Agricultural crops are planted with trees used for wood production.

Table 29.—Some Prominent Agroforestry Systems in Developing Countries

Southeast Asia	Southern Asia	Mediterranean and Middle East	Eastern, Central, and Humid West Africa	Arid and semiarid West Africa	American Tropics
1. Agro-silviculture					
1. Commercial trees among crops 2. Fruit/shade trees among crops 3. Live fences 4. Shelterbelts 5. Taungya 6. Shifting cultivation systems 7. Intercropping in plantation crops (rubber, oil palm, coconut)	1. Taungya 2. Plantation crops + arable crops 3. Commercial trees and fruit trees with crops 4. Live fences + shelterbelts 5. Various trees on farmlands for productive functions 6. Various forms of shifting cultivation 7. Medicinal plants + agriculture species	1. Olive + cereals (on terraces, 'banquettes', 'cuvettes', etc.) 2. Poplars along irrigation canals 3. Trees for sand dune reclamation 4. 'Huertas' - small plots irrigated crops + fruit trees 5. Aromatic, medicinal and fruit trees with crops	1. Taungya 2. Cacao/food crops/forest complex 3. Plantation crops (oil palm/rubber) and root crop complex 4. Coffee + banana 5. Mixed perennial crops 6. Gum arabic + millet 7. Shifting cultivation/bush fallow systems	1. Use of trees on farmlands for protective role (windbreaks, dune fixation) 2. Productive + protective role of trees on farms (*A. albida*/*Leucaena* +agriculture crop systems)	1. Trees in perennial cash crops (coffee, cacao, tea) 2. Trees for organic matter and mulch with annual crops 3. Tree live fences 4. Windbreaks and shelterbelts 5. Trees as support for climbing commercial crops 6. Taungya 7. Shifting cultivation systems
2. Silvo-pastoral					
1. Pasture in forest plantation 2. Pasture in secondary forests 3. Commercial trees in pastures 4. Fruit/shade trees in pasture 5. Fodder trees 6. Coconuts + pasture	1. Pasture under trees 2. Plantation crops + cattle grazing 3. Fodder trees and shrubs 4. Fruit trees and commercial trees in pastures	1. Oak forest + grazing 2. Pig breeding and forestry 3. Range land improvement	1. Gum arabic + livestock 2. Plantation crops (coconut/cashew) + pasture	1. Nomadic/semi-nomadic/transhuman 2. Sedentary livestock grazing systems/browsing systems 3. Fodder tree/shrub systems	1. Trees in pasture 2. Pasture in natural regeneration forest 3. Trees lopped for fodder 4. Trees used for browsing
3. Agro-silvo-pastoral					
1. Crops and grazing in plantations 2. Agriculture tree crops + grazing in forest plantation 3. Multipurpose trees with crops/animals 4. Integrated farming systems with agriculture plantation crops (rubber, coconut, oil palm)	1. Plantation crops + arable crops + livestock 2. Agriculture tree crops + grazing in forest	Range land management	1. Coconuts/other plantation crops + food crops + grazing 2. Coffee + banana + dairying 3. Horticultural complex systems 4. Plough culture complex systems	1. Forestry dominating (forest lands) 2. Agriculture dominating (crop lands) 3. Livestock dominating (crop lands)	1. Agriculture plantation crops (coconut, rubber, fruit, trees) with crops and pastures

Table 29.--Some Prominent Agroforestry Systems in Developing Countries—Continued

Southeast Asia	Southern Asia	Mediterranean and Middle East	Eastern, Central, and Humid West Africa	Arid and semiarid West Africa	American Tropics
4. Home gardens					
Various forms of multispecies combination	1. Multistorey plant canopies in humid regions 2. Arid/semiarid systems	Mainly in large cities	Various forms	Various forms	Various forms
5. Others					
1. Silviculture in mangrove forests 2. Agri-silvi-fishery 3. Trees on bunds in fish breeding ponds 4. Swidden farming 5. Fuelwood agroforestry	1. Mixed perennial cropping 2. Irrigation systems 3. Various site-specific systems 4. Fuelwood systems	1. New system in Morocco (spice plantation for erosion control) 2. Agriculture + forestry 3. Fruit trees in deserts 4. Mushroom cultivation in forest	1. Pastoral systems with corral farming (highland/lowland) 2. Mixed perennial cropping	1. Oasis 2. Irrigation systems 3. Various site-specific systems	Mixed perennial cropping

SOURCE: Anonymous, "A Global Inventory of Agroforestry Systems," *Biomass* :241-245, 1983.

Photo credit: S. Hecht

Rubber trees interplanted with a cover crop of *Pueraria phaseoloides* and grazed by cattle is one type of agroforestry system

Agroforestry systems attempt to optimize ecological and economical interactions between various components (trees and shrubs/crops and animals) to obtain a higher, more diversified, and/or more sustainable total production than is possible with any single land use. Typical characteristics of such systems are: 1) two or more species of plants (or plants and animals), at least one of which is a woody perennial; 2) two or more outputs; and 3) a production cycle of more than 1 year.

Agroforestry can provide many goods and services. Depending on the particular situation, it may:

- increase and improve food production yields;
- produce firewood and a variety of other raw materials from shrubs and trees for farmers' subsistence, for local sale, and sometimes for export;
- protect and improve the soil's productive potential;
- improve social and economic conditions in rural areas by creating jobs and income and reducing risks; and
- develop land-use systems that draw on both modern technologies and traditional local experience and that are compatible

with the cultural and social life of the people concerned.

Classification and Assessment

Many reviews of traditional agroforestry systems and practices in the Tropics and subtropics have been published,* but most are only descriptive accounts. Rarely are any quantitative data included on the number of people or areas involved. Nor have many in-depth analyses of the environmental and economic advantages or disadvantages of the systems been conducted. The reviews do show, however, that agroforestry has been practiced for a long time with apparent success in almost all parts of the dry and wet tropical and subtropical worlds.

Agroforestry systems have been classified in different ways according to 1) physical structure, 2) temporal arrangement, 3) relative importance and role of components, 4) production aims/outputs, and 5) social and economical features (see 11,19,24,41,42). The following discussion of agroforestry is based on three socioeconomic production categories: commercial, intermediate, and subsistence (26). The divisions among categories are not discrete; rather they represent a continuum of production systems. Nevertheless, it is a suitable basis for discussing potentials and problems of further development and large-scale implementation of agroforestry.

Commercial agroforestry systems typically have as their aim the production and sale of crops, often a single commodity. These systems have been the object of systematic development efforts by horticultural, agricultural, or silvicultural institutions. Commercial tree crops (e.g., coconut rubber or oil palm) are interplanted with food crops or forage crops, or the understory is grazed by animals. The use of commercial timber species in conjunction with cacao is better developed than with almost any other cash crop system. Grazing cattle under plantation trees has attracted much attention as a promising way of increasing total yield from the land. An example is the Jari Project in Brazil, where seeding the pine plantation (*Pinus caribea*) with forage grass (*Panicum maximum*) reduced the need for weed control. The cattle then increased the total income from the system (21).

Many commercial timber and pulpwood plantations in the Tropics have been established through the "taungya" system. Farmers or forest laborers are allowed to grow crops for a few years during land preparation and early plantation phases. In exchange, they weed and care for the young trees. After an agreed-upon period, the farmers move on. Taungya has been used for more than a century and has been applied throughout the Tropics. Although well-planned taungya can provide a sequence of new ground for shifting cultivators, it removes the land from agriculture for a period dictated by the biology and economics of the forest crop and not by the needs of farmers or forest laborers.

The widespread use of this system and its many local variations is a clear indication of its success (25). The practice has been successful with *Terminalia, Triplochiton,* and several *Meliaceae* in West Africa; *Cordia* in Surinam; *Tectona* in Trinidad; and *Swietenia* in Puerto Rico (45). In Nigeria, the system has been applied in both wet and dry zones for tree and food production. In that country, it has been credited with providing enough food for about 700,000 people, or about 1 percent of Nigeria's food needs (13).

The increased use of commercial, commodity-oriented agroforestry is attractive in theory. However, the areas under perennial agricultural tree/shrub crops occupy about 8 percent of total arable area in developing countries today (27). Of this, only a minor part is used for intercropping or grazing. Another 2 million hectares of perennial agricultural tree plantations could be established by the year 2000 without encountering serious marketing problems (38). But this approach has limited potential for substantially alleviating land problems. Since commercial agroforestry will be introduced only where opportunities for profits are clearly perceived, it is unlikely to be used on infertile land or by people who are not entrepreneurs. This objection applies less to timber plantation land, where small improvements in taungya could produce significant increases in food production. Forest plantation lands could then support considerably more people than they do now.

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*For Latin America see Budowski (7); Weaver (46); Ampuero (2); de Las Salas (12); Wilken (47); Budowski (8). For Africa see FAO (14); von Maydell (43); Seif el Din (36); Okigo (30); Iyamabo (23); IITA (22); Poulsen (33,34). For Asia see Atmosoedaryo and Wijayakusumh (4); Generalao (18); Ahmad (1); FAO (15).

Intermediate agroforestry systems are where farmers with small to medium sized landholdings combine production of perennial crops for cash with annual crops for subsistence. Some of these systems are oriented toward commercial production, but they are small and the land is operated by individual farmers. Others are similar to subsistence systems. An example is the combination of gum arabic trees (*Acacia senegal*), which can provide good cash income to farmers, with millet in the Sudan. Another intermediate level agroforestry system occurs when commercial firms enter into contracts with small- and medium-scale farmers to produce raw materials. The British-American Tobacco Co. in Kenya has contracts with farmers who grow tobacco and the fuelwood needed for curing it, together with their own food crops.

Coffee forms the economic basis for many integrated land-use systems in this category, particularly on fertile soils in tropical uplands. In the East African highlands, multistory production is common. Timber trees such as *Albizzia* and *Grevillea* shade coffee interplanted with bananas and beans (33). Similarly, in Costa Rica coffee is grown under the shade of both timber trees (*Cordia alliodora*) and multipurpose trees (*Erythrina* spp.) (7,8). Another important crop in tropical small-holder agroforestry is coconut. Planting food crops and grazing cattle under coconuts are common practices in the wetter parts of Sri Lanka, India, Southeast Asia, and the Pacific regions (28).

Most of the economically and ecologically successful examples under this category are found in areas having relatively fertile soils, good communications, and existing market infrastructure. But many obstacles can be encountered when expanding permanent cash crops into less favorable areas, where infrastructure and markets are underdeveloped, where land tenure is uncertain, or where the environment imposes serious restrictions on intensive land use. Still, there is promise for improving existing systems through the introduction of improved varieties of tree crops, fruit trees, and compatible food crops, as well as application of fertilizers.

Subsistence agroforestry systems are oriented toward satisfying the basic needs of farmers for food, fuel, and shelter, with some products sold for cash income. Such systems are practiced by a large portion of the population of the tropical world, from livestock herders in semiarid areas to shifting cultivators in rain forests. These systems usually are practiced where serious ecological and/or socioeconomical constraints exist. Infertile soils, erosion, and/or drought can be major physical limitations. Insecure land tenure and lack of infrastructure, capital, extension services, and education are common socioeconomic constraints.

Many different subsistence agroforestry systems exist. Shifting cultivation and bush fallow are practiced in many forms throughout the tropical world. One well-known form of permanent traditional agroforestry is the home gardens of Southeast Asia, characterized by a multistory mixture of many species of trees, shrubs, climbers, palms, tubers, and often animals (pigs and poultry) (16). Other agroforestry in Asia integrates rice production with trees for windbreaks, boundary demarcation, and fuelwood production (6,16).

Oases are a prototype of agroforestry in arid lands. They contain ponds to water livestock as well as an upper story of multifunctional trees and a lower story of agricultural or horticultural plants. Though only comprising a small area endowed with water and fertile soils, they can be extremely well-balanced human ecosystems with species mixture, multistory structure, and near-perfect recycling processes (44).

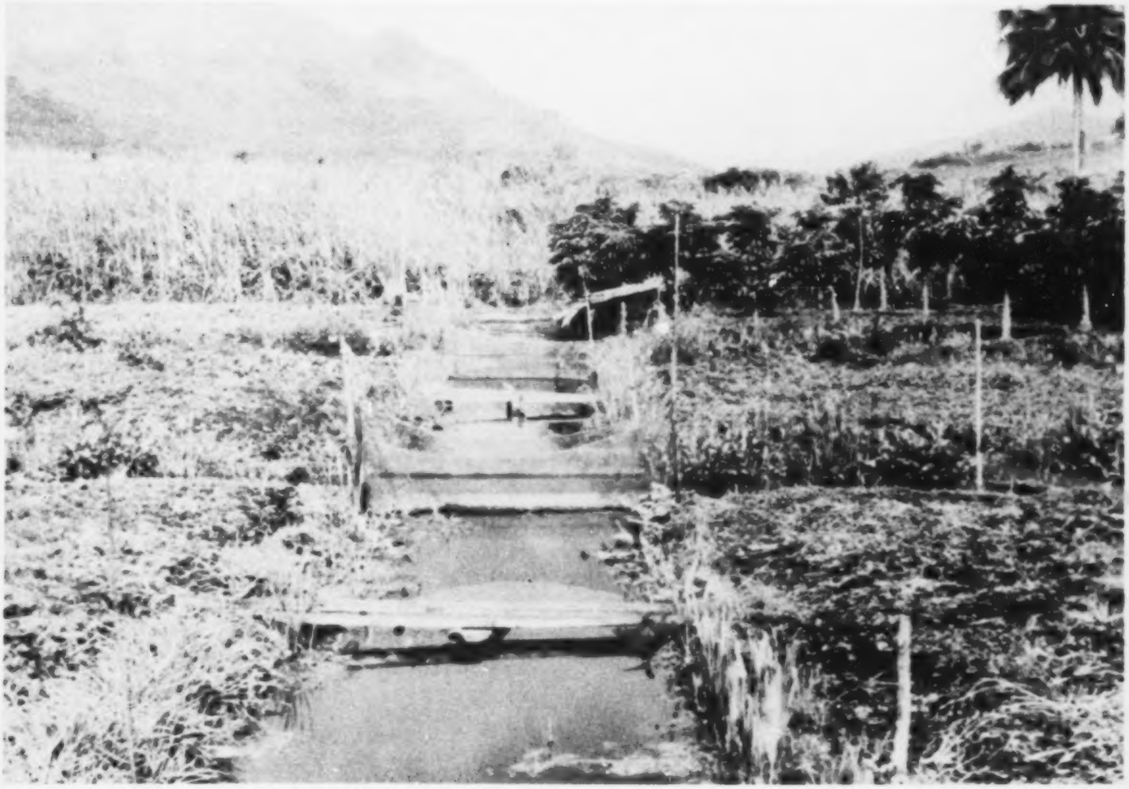


Photo credit: K. Parker

Chinampas in Mexico are centuries-old food production systems used where water is available year round. Narrow irrigation/drainage canals surround the plot and control water supply; mud dredged from canals serves as organic fertilizer; aquatic vegetation serves as "green manure;" fish that colonize the canals provide additional protein; trees planted along the canals hold the soil in place as well as providing other products

Millions of people practice agroforestry in areas with serious physical and socioeconomic constraints. The problem of improving the productivity and sustainability of these people's agriculture and agroforestry methods is of an entirely different magnitude than that of improving commercial and intermediate agroforestry systems. Reaching farmers can be difficult, and where subsistence farmers can be reached, they need to be convinced that the costs, risks, and benefits of new technologies are favorable. The time between planting a tree and achieving significant yields may involve risks that subsistence farmers cannot take. It also can be difficult to convince land users to make long-term investments when land tenure is uncertain. Subsistence agroforestry holds great potential for improving land use but has urgent need for technology improvement.

Technology Issues

In general, the concept of agroforestry as a sustainable approach to land use is sound. The aim is to create productive farming systems able to supply an increasing and sustainable output of basic needs, including cash. Maintaining soil fertility, preventing erosion, moderating microclimate, and other environment-enhancing roles of the tree/shrub component apparently do help sustain production.

A growing body of information exists on the various agroforestry technologies, but this is mainly descriptive and qualitative. Most scientists' interest has been in the tree/shrub component (e.g., potential tree species, their use, and management) because of the novelty of using trees and shrubs in agricultural and pastoral lands.

During the last 5 years, many agroforestry research projects have been initiated at university forestry departments and forestry research institutes. These generally study the long-term economic and ecological productivity of various trees, planted at different spacings, and combined with a food crop, which is often used as a "test" crop to quantify the competitive or soil-improving influences of the tree.

Only certain trees and crops prove to be compatible. Rubber trees, for instance, produce so much shade that underlying pasture often becomes useless within 3 years. Oil palm soils are often clayey and wet and animals tend to compact the soil and damage tree roots (17). Some crops such as sorghum, millet, and pigeon pea are highly competitive with other plants and, thus, may not be suitable for intercropping. Other crops—maize, cotton, and dry rice—are less competitive and can be intercropped. Each system has complex problems of intraspecific and interspecific competition. The aim of experimental research is to optimize combinations of agriculture, pastoralism, and forestry over space and time.

Tropical research and development organizations have become much more interested in multipurpose trees. The legume family has attracted particular attention. In general, legumes, through their bacterial relationship, can improve soil fertility and produce good-quality fuelwood as well as leaves and pods with fodder and food value. Different legume species also are adapted to a wide range of ecological conditions. Many multipurpose species are found in the legume genera *Acacia* and *Prosopis*. Several nonlegume multipurpose species are equally interesting because of their general versatility, adaptability to less favorable sites, and yield of valuable products. An example is the neem tree (*Azadirachta indica*) which originated in the dry zones of Asia. It is an excellent timber, fuelwood, and shade tree and produces tannins, insecticidal chemicals, and fuel/lubricant oil (35).

The greatest potential for improving agroforestry systems lies in the practically unexplored field of genetic improvement of multipurpose trees and shrubs (26). Selecting the species and varieties that are best adapted to particular purposes and site conditions for which the agroforestry systems are intended is the first step. Traditional agroforestry systems have been doing this gradually for centuries, but now with modern communications and techniques for reproducing, transporting, and testing varieties, it is possible to greatly accelerate the process.

Because the scientific attention to multipurpose trees is so new, examples of the gains that can be achieved by this selection and matching process are rare. The interest in single-purpose use of trees is older, and gains with these illustrate the potential for multipurpose trees. For example, results from 32 sites in 18 countries show that productivity gains of several hundred percent could be achieved in eucalyptus trees simply by selecting the best-adapted provenances for prevailing conditions (31).

The second step, which can begin before the first is completed, is tree breeding—crossing plants to combine particular desired characteristics, such as fodder and fuel production quantity and quality, rooting characteristics, phenology favorable for interplanting with annual crops, nitrogen-fixation, pest resistance, drought resistance, or the ability to withstand other stresses.

The potential for agroforestry systems improvements to be adopted on a large scale by farmers and pastoralists is difficult to assess. If the relevant land-use problems have been identified and an ecologically, economically, and socially well-adapted agroforestry solution is demonstrated to be feasible, then agroforestry improvements may be adopted. However, finding locally acceptable solutions to problems that are perceived by farmers is crucial. Sophisticated trials on the best spacing of trees over crops are, for example, not particularly relevant if farmers are not interested in that particular tree species.

The constraints and problems encountered in developing and disseminating agroforestry systems are many. Millions of farmers and landless people are spread over vast expanses of tropical lands. Rapid population growth, insecure land tenure, erosion, droughts, floods, declining soil fertility, lack of infrastructure, political instability, illiteracy, and other development problems often characterize those broad regions where agroforestry approaches have a potential role to play. Therefore, agroforestry development cannot occur in isolation from general social and physical constraints on rural development.

Constraints and Opportunities

Agroforestry techniques can be used to address particular land productivity problems. However, most information on the technique is qualitative and advocative. Present research and field implementation efforts are more ad hoc than systematic.

Critical analyses of agroforestry's constraints and opportunities must be made if it is to benefit from application of the scientific method. Systematic quantitative information can provide a basis from which researchers can formulate hypotheses and design efficient research strategies to develop new agroforestry systems, refine old ones, and adapt proven ones to other areas. This is necessary to ensure that only technologies with high probability of success are brought to large-scale field implementation.

The effort to organize and assess existing national and international experience in traditional agroforestry technologies and to identify promising technologies for further development is under way at the International Council for Research in Agroforestry (ICRAF). Technologies that need refinement and farm validation include alley cropping, improved fallows, live fences, contour hedges, mulch production with tree species, and fodder production. Some such programs already exist, but efforts should be made to strengthen these (table 30).

Table 30.—Organizations That Work on Agroforestry Systems

1. International Council for Research in Agroforestry
2. Centro Agronomical Tropical de Investigacion y Ensenanza (CATIE)
3. International Tree Crop Institutes (U.K., U.S.A., and Australia)
4. Nitrogen-Fixing Tree Association
5. National Academy of Sciences (fuelwood and legume tree species)
6. Commonwealth Forestry Institute (information, research, and training)
7. East-West Center (dissemination and exchange of agroforestry information)
8. United Nations University (workshops and research programs at cooperating institutions)
9. Some components of UNESCO/MAB research program
10. Some developed country universities
11. Some CGIAR institutions (e.g., IITA in Nigeria on alley cropping and CIAT in Colombia on *Leucaena* and *Erytherina*)
12. FAO's Panel of Experts on Forest Gene Resources (data collection and assessment)

SOURCE: B. Lundgren, "The Use of Agroforestry to Improve the Productivity to Converted Tropical Land," OTA commissioned paper, 1982.

Since agroforestry cuts across several disciplines, it requires an integrated and multidisciplinary approach. Agronomists, foresters, ecologists, sociologists, anthropologists, and experts in other related disciplines have accumulated much data on various tropical mixed-cropping systems. Such information can become the foundation for research programs to explore ways to integrate sustainable production of food, forage, and fiber needs on appropriate lands. However, too little communication or coordination occur among these disciplines to formulate a strategy for development of agroforestry technologies. This constraint would be alleviated if interdisciplinary teams were established to conduct research on integrated land-use systems (26).

Agroforestry needs an institutional home to ensure its implementation. It is considered a subdivision of forestry, but forestry institutions deal with forest land. They seldom address the problems facing individual users of small and medium size holdings of cultivated lands. Forestry institutions, in general, do not have the range of expertise needed to develop agroforestry's full potential. The major potential for agroforestry lies in the integration of trees into agricultural and pastoral lands. The development of these lands is the mandate of agricultural institutions, which are not explicitly mandated to deal with agroforestry.

Rigid boundaries between disciplines affect funding of agroforestry research, development, and implementation. Forestry and agriculture often compete for both funds and land. In international agencies, agricultural divisions are better institutionalized, more prestigious, and, thus, better funded than forestry divisions. The forestry funds that do exist usually are channeled to conventional forestry activities.

The ratios of international financial support for research in tropical agriculture, forestry, and agroforestry, respectively, are about 200:10:1 (26). This may underestimate the relative magnitude of agricultural research support. Although the importance of research is clearly recognized in agriculture, the attitude of development assistance donors toward research in forestry is cool. Thus, as long as agroforestry funding is channeled through forestry departments, little hope exists that sufficient research funds will be available. A thorough rethinking and revision of the appropriate institutional home for agroforestry is needed.

The large-scale promotion of agroforestry would require incentives to encourage farmers to adopt practices that involve initial risks and delayed returns. Integrating trees into agricultural or pastoral systems is unlikely to succeed where short-term, insecure leases for use of land are prevalent, where trees automatically become the property of the government, or where nonrestricted communal grazing or tree cutting rights exist. Neither are farmers likely to achieve large-scale cash crop production of wood (i.e., fuelwood, poles, pulpwood, etc.) where prices are set so low that growing trees is not profitable.

To alleviate these constraints, tropical governments will need to identify and remove constraints in land tenure and provide incentives and extension services. Incentives may take the form of credits and loans that reduce initial capital outlay and minimize risk of failure. Extension services can facilitate supply of materials, train farmers, and make followup visits to monitor progress of agroforestry development. Unfortunately, forestry and agroforestry extension efforts often suffer from: 1) lack of staff with adequate training, 2) lack of networks of on-farm demonstration plots, 3) inconsistent efforts, 4) difficulty obtaining good seeds of multipurpose tree species for mass distribution to farmers, and 5) lack of infrastructure.

As institutional interest and support for agroforestry increase, it is necessary to take steps to ensure that the enthusiasm does not lead to disappointment and a sharp reduction of support. Development assistance agencies and research institutions have not begun, collectively or individually, to formulate a strategy to assure that the necessary and sufficient steps are taken to develop the potential of agroforestry.

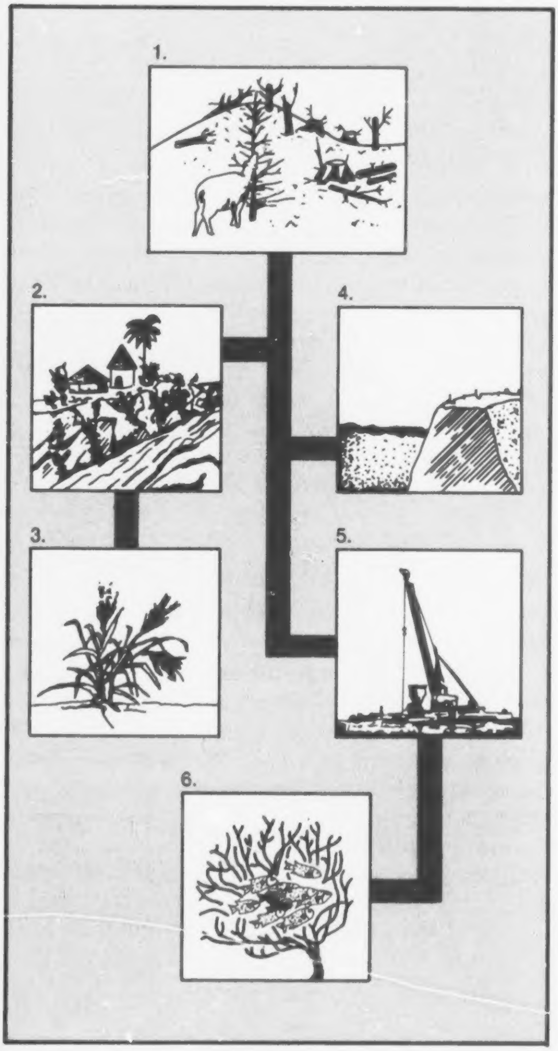
WATERSHED MANAGEMENT

Background

In an undisturbed watershed, the disposition of rain and snow melt is determined by a complex interaction of terrain, soil, climate, geology, and vegetation. Unfortunately, some common land uses seriously disturb the vegetative cover so that both the amount of water that upper catchments can hold temporarily during prolonged or heavy rains and the proportion of rain that percolates into the soil are seriously reduced. This results in much greater variations in the seasonal river flows, greater sediment loads during peak flows, and often a greater proportion of the total rainfall running off before it can be used by trees or crops (fig. 28).

For example, denudation of water catchment areas in the Indus River system has led to

Figure 28.—Effects of Poor Watershed Management



Overgrazing, deforestation, misplaced cultivation, or carelessly built roads in the upper catchment area (1) can have devastating effects downstream. These can include: gullying and floods leading to destruction of farmland and villages (2); drops in flow during the dry season and consequent loss of crops (3), and siltation of irrigation systems and reservoirs (4), docks and canals (5) and coral reefs (6), leading to loss of water supply and hydroelectric power, costly dredging, and damage to fisheries.

SOURCE: World Conservation Strategy, 1980.

floods far higher in the last 25 years than during the previous 60 years and has increased serious silting in the reservoirs and canals of Pakistan's irrigation system (32). In recent years in India, the cost of repairing flood damage below the Himalayan catchments has been, on average, US $250 million a year, in addition to losses of production and livelihood suffered by millions (39).

Technologies can probably be developed and implemented to help reduce these economic and human costs. The solution to these problems of land misuse depends foremost on developing improved methods of land use that are both more profitable to local communities and also give appreciably better control of the water flow. Soil conservation structures (e.g., terracing), revegetation, and appropriate farming systems are technically adequate to contain the current land degradation trend, but many of these techniques are too expensive for the farmers living in the upland areas.

Watershed Management

Description

Watershed management is concerned with controlling water flow above and below the Earth's surface from the upper to lower regions of drainage basins. Management of the upper watersheds aims to maintain or to improve the timing, quantity, and quality of water that is used in more intensively developed lowlands.

The natural vegetation on tropical mountain slopes that receive high rainfall is closed canopy evergreen forests, sometimes interrupted by shallow-soiled grass or swamp areas. Evergreen forests provide temporary storage for heavy rainfall, thus delaying water's movement into streams and reducing peak storm flow. The temporary storage occurs partly on the wetted canopy, partly in the deep forest ground-litter, and partly in the topsoil made porous by vegetation and soil fauna. Some water drains through these porous surface layers to streams. Some water infiltrates to recharge ground water and thus maintain dry-season spring flows. Some water is evaporated from the wet canopy and some is transpired back into the atmosphere through the foliage.

Watershed management includes soil conservation, road planning, contour cultivation, grassed waterways, cutoff drains, grass planting on steep banks, and other techniques to control water's impact. Soil stability, agricultural productivity, and the quality of water supplied to the lower reaches of the watershed can thus be maintained. Watershed management is an economic necessity where there is investment downstream in reservoirs for hydropower and irrigation or densely settled areas in zones of flood hazard.

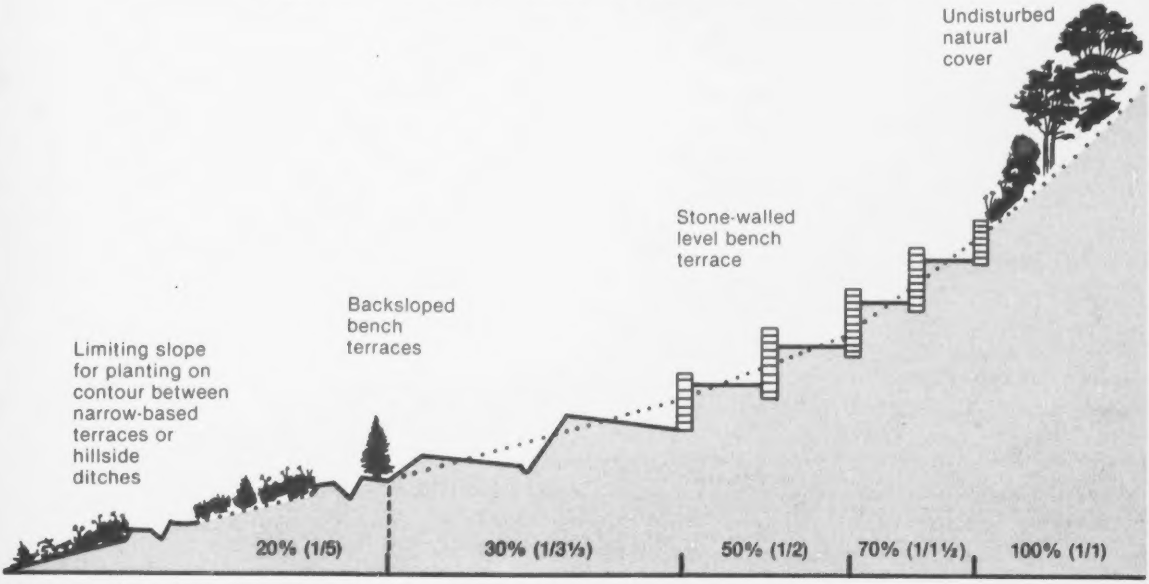
General Technical Principles

The choice of technologies for watershed management and rehabilitation varies with topography, accessibility, and population density. One of the best ways to protect downstream populations from excessive siltation and flooding is to maintain forests on all slopes steeper than 100 percent grade (45°). Where steep slopes have been cleared, they should be closed to livestock, protected from fire, and then stabilized by planting trees for fuel and fodder. In some cases, simple protection will suffice to permit natural regrowth. For slopes between 100 percent and 20 percent, land should not be cultivated except where the soil is stable and deep. Here, cultivation can be done safely only where level or preferably backsloping terraces are maintained. For slopes less than a 20 percent grade, a variety of agricultural technologies for minimizing soil loss can be used (fig. 29).

In sparsely populated watersheds, where there are few or no people living in the upper regions of river basins, tropical watershed management is a matter of maintaining or restoring the vegetative cover that controls water flows. If forests are intact and populations are low, intensive management is not necessary. The best and least expensive method of protecting these forests is to designate them parks or protected areas. However, effective park management can be difficult to obtain. It should be based on a comprehensive plan that takes into account the previous, current, and future resource needs of people who live around and below the protected forest.

The greatest watershed problems in the Tropics, however, are not in the upper sparsely populated reaches of river basins. They are in **populated watersheds,** where the upper regions

Figure 29.—Slopes and Appropriate Conservation Measures



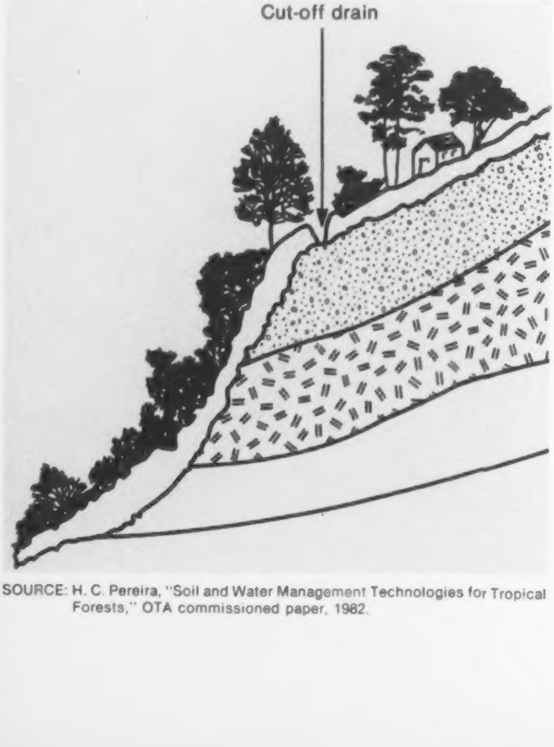
SOURCE: H. C. Pereira, "Soil and Water Management Technologies for Tropical Forests," OTA commissioned paper, 1982.

are farmed and grazed, and where maintenance of natural closed forest cannot be accomplished without displacing substantial numbers of people.

In some cases watershed management technologies can be used without displacing people from upland areas. For example, where forests cover steep escarpments below settlements, runoff from the upper slopes can overload the forest soils and cause large-scale landslips, especially on geological dip-slopes (fig. 30). Such landslips are common in Nepal, parts of Zaire, and in other places where sedimentary rock formations are tilted. It may be possible to stabilize these areas through reforestation and cutoff drains, which intercept and convey runoff to stable drainage lines and, thus, protect the soils from saturation. These drains need to be protected as well, possibly with tree cover.

The most critical need for watershed management occurs in the forests immediately above the limits of cultivation (32). Often, these are under great pressure from population growth. Such forest areas are usually too steep, shallow-soiled, and rock-encumbered for continuous cropping. Yet, agricultural communities have in many countries established traditional rights for grazing or for collection of fuel and fodder from these lands. Massive overgrazing inflicts most damage, often preventing the emergence of any effective ground cover. These activities promote erosion, which consequently forms major gulleys (29). Some areas are so steep and unstable that the only option is to prohibit all active use. In moist forest areas, if soil nutrients have not been eroded or leached away, the ability of the land to recuperate can be high. However, sustainable alternatives must be found for the displaced people, or they will, sooner or later, begin to overuse the slopes again.

Figure 30.—Cut-Off Drain to Protect Steep Forested Scarps From Landslip Hazard



SOURCE: H. C. Pereira, "Soil and Water Management Technologies for Tropical Forests," OTA commissioned paper, 1982.

Tropical forests on land with easy access and gentle topography are likely to be cleared for agriculture or other land uses. When such areas are logged and cleared, soil and water management problems do occur. Governments should restrict the use of more damaging heavy equipment to well prepared roadways. Cable ways, winching, and use of lighter logging and land preparation machinery, though likely to be more costly, can be less damaging to the soil. Operational trials with equipment designed to reduce soil damage should be conducted to test and demonstrate its utility (32).

Specific Technologies

The primary technologies available to deal with watershed problems are those associated with alteration of the surface geometry, revegetation, and improved farming.

SOIL CONSERVATION STRUCTURES

A common method to reduce soil erosion from hills in the humid tropics is to change the slope steepness and length. For example, a steep slope can be changed to many continuous flat strips running along the contour across a hillside (terraces), or a long slope can be changed to a series of shorter slopes by using discontinuous types of structure. The objective of both measures is to divert runoff along the contour toward protected drainage channels or waterways at a velocity that reduces erosion.

These and other technologies not only have physical requirements but financial, labor, and land-use rights requirements. The cost of various conservation structures per unit area depends on slope, soil, type of terraces, width of bench, presence of rocks or tree stumps, and the tools needed to build them. Since the structures can be expensive, a cost-sharing or subsidy scheme may need to be introduced by the government. Farmers often are reluctant to invest the time and effort to build such structures because of insecure land tenure. Further, labor often is not available.

Few critical, full-scale studies of terracing have been reported from the Tropics. Many small runoff plot measurements are made, but these do not reproduce the conditions of cultivation by oxen or tractor that determine infiltration, runoff, and erosion on a practical scale.

REVEGETATION

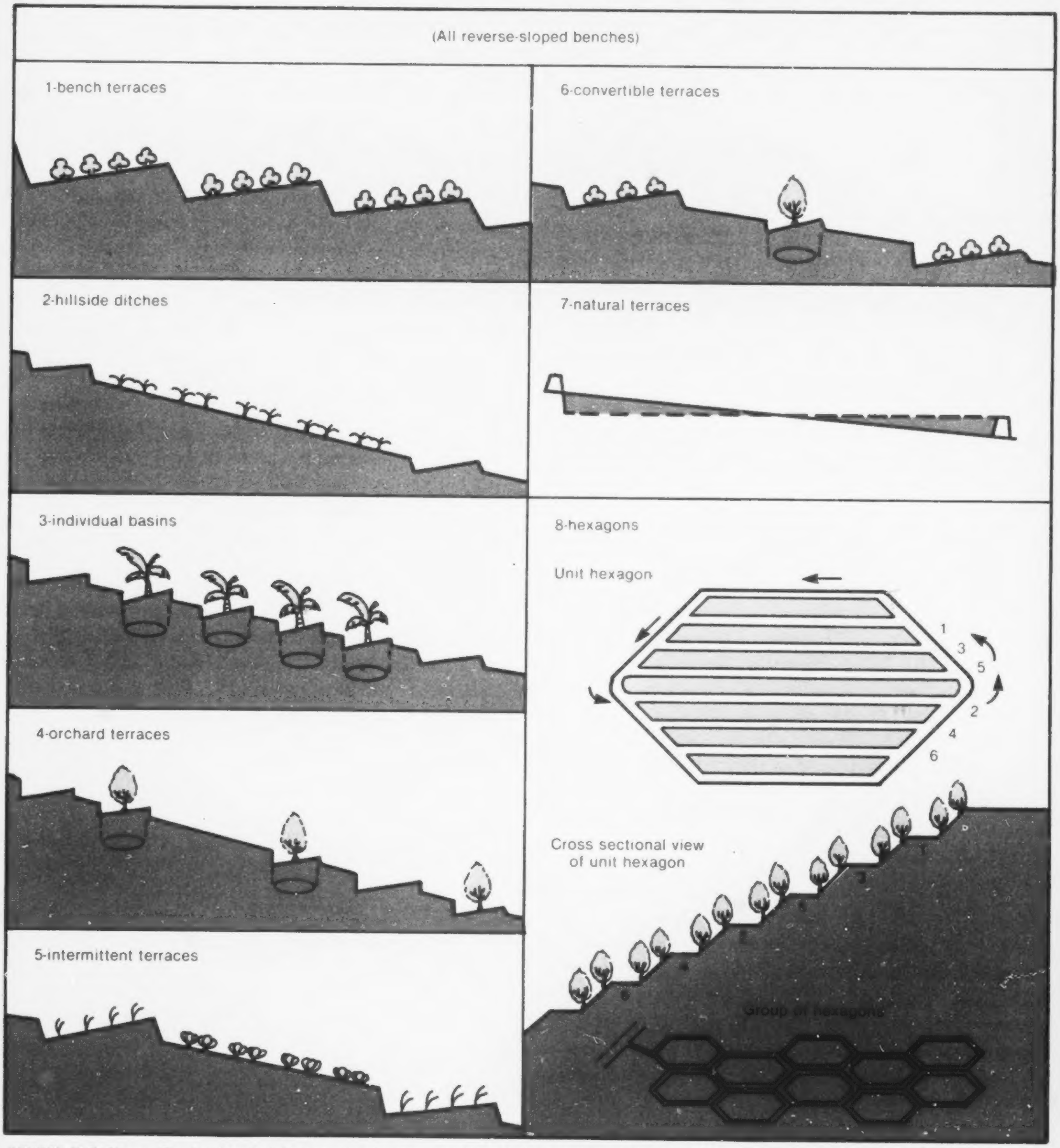
Steep mountain areas that have been cleared should be reforested to protect water and soil resources. If the objective is to stabilize soil and streamflow, the least expensive method is to protect the area from grazing livestock and fire so it can regenerate naturally. In some cases where erosion has been severe, natural regeneration needs to be augmented by seeding with grasses, legumes, and shrubs. More expensive reforestation investments are appropriate where the objectives include production of fuel, fodder, and timber of desirable species; where grasses and shrubs will not provide

Terracing

Terraces not only control erosion but also can be used to facilitate irrigation and drainage, as well as cultivation. Reversed-slope benches, continuous or discontinuous, differ in width to suit different crops and slopes. Benches improve drainage by concentrating runoff at the outside of the bench and then drain it along a controlled lateral gradient to a protected waterway. They are suited to annual, semipermanent, and mixed crops and can be applied on slopes up to 30°. Variations of conservation structures include (fig. 31):

- **Bench terraces:** a series of level strips running across the slope supported by steep risers. These can be used on slopes up to 25° and are mainly used for upland crops.
- **Hillside ditches:** a discontinuous type of narrow, reverse-slope bench built across the hill slope in order to break long slopes into many shorter ones. The width of the cultivable strips between two ditches is determined by the slope of the land. They are inexpensive, flexible, and can be built over a period of years. This treatment can be applied to slopes up to 25°.
- **Individual basins:** small, round benches for planting individual plants. They are particularly useful for establishing semipermanent or permanent tree plots to control erosion. They should normally be supplemented by hillside ditching, orchard terracing, and crop covering.
- **Orchard terraces:** a discontinuous type of narrow terrace applicable on steep slopes up to 30°. Spacing is determined by distance between trees. Spaces between terraces should be kept under permanent grass or legume cover.
- **Intermittent terraces:** bench terraces built over a period of several years.
- **Convertible terraces:** bench terraces with the spaces between terraces planted with tree crops.
- **Natural terraces:** constructed initially with contour embankments (bunds) 50 cm high on slopes not over 7° and on soils having high infiltration rates.
- **Hexagons:** special arrangement of a farm road that surrounds or envelops a piece of sloping land treated with discontinuous terraces which are accessible to four-wheeled tractors. This treatment is primarily for mechanization of orchards on larger blocks of land and on slopes of up to 20°.

Figure 31.—Cross-Sectional View of Eight Types of Conservation Structures


(All reverse-sloped benches)
1-bench terraces
2-hillside ditches
3-individual basins
4-orchard terraces
5-intermittent terraces
6-convertible terraces
7-natural terraces
8-hexagons
Unit hexagon
1
3
5
2
4
6
Cross sectional view of unit hexagon
Group of hexagons

SOURCE: T. C. Sheng, "The Need for Soil Conservation Structures for Steep Cultivated Slopes in the Humid Tropices," *Tropical Agricultural Hydrology*, R. Lai and E. W. Russell (eds.) (New York: John Wiley & Sons, 1981), pp. 357-372.

enough runoff control; or where protection from fires cannot be sustained indefinitely.

Efforts to establish tree cover on long steep slopes must overcome the erosion and landsliding that may be common to those sites. For instance, primitive dams made of rock, soil, and, if available, tree stems and branches can be built in gullies to slow water and trap soil until trees can be established. Channels and walls can be built to divert water flow from vulnerable areas. Water-spreading techniques can be used to distribute runoff water over relatively flat areas, reducing its erosive potential. Terracing, contour hedges and furrows, and low retaining walls can control sheet erosion. To establish trees it may be necessary to use contour planting, with graded hillside bunds or narrow-based terraces at suitable intervals to lead runoff into prepared drainage lines.

Perennial tree crops such as tea, oil palm, rubber, or coconut can be almost as effective as natural forest to regulate water flow, provided that soil conservation measures such as terraces and sound engineering of roads are included. Stormflow control, however, may not be fully restored. In Kericho, Kenya, where measurements of runoff from a tea plantation were taken, stormflow peak, although small, remained twice that from a comparable undisturbed forest. Thus, if large areas of forest are to be converted to tea or other estate crops, additional reservoir storage will be needed to modulate peak flows (32).

The same is true for fast growing forest plantations with short harvesting schedules. Care is needed during harvesting to minimize negative impacts. Selection of tree species also is important. *Eucalyptus,* for instance, planted close together will eliminate all vegetative ground cover and this can accelerate soil erosion (40). Pure stands of trees that may have their leaves closed during rainstorms, such as *Leucaena,* provide only partial soil protection (5). Therefore, it may be necessary to include a second story of shrubs to minimize the impact of rain drops falling through or from the canopy.

In areas with a dry or seasonally dry climate, flood control and ground water recharge may not be considered so important as maximizing the amount of water delivered to reservoirs or to farms and cities in the lower regions of the watershed. In this case, watershed managers may decide that the closed forest consumes too much water and may prefer to maintain a grass cover, since evapotranspiration loss is greater from tall trees than from low shrubs or grass. On the other hand, in some dry, mountainous areas, trees that collect moisture on their leaves from wet air are the best mechanism to recharge ground water (9). Overall, the negative and positive impacts of grass and tree cover under tropical conditions are poorly known. Grass cover may increase the amount of runoff and flow rates may not be modulated, thus making dams necessary. Improvements in the science of hydrology are needed to provide better data to calculate the tradeoffs of management options.

Complete grass cover is an acceptable vegetation for tropical watersheds only where dry season grazing and burning can be rigorously controlled. Thus, watershed management becomes livestock and fire management as well. A strategy to reduce livestock damage in watersheds should include improving draft power and milk production per head so as to encourage farmers to keep fewer and better quality animals. This can be accomplished by introducing superior animals, by providing effective marketing systems, and by establishing livestock exchange programs. The danger exists that farmers will be encouraged to keep more livestock in addition to or in place of farming.

Fire is used to eliminate old grass growth and improve the quality of grasses for grazing. However, repeated burnings can damage soil by destroying soil organic matter and consequently reducing soil microbiological populations. Human-induced fire is common in grasslands and is difficult to control. If grass is going to be the primary vegetative cover or even the cover while trees are small, methods must be devised to control fire as well as regulate its use.

Encouraging stall or pen feeding also reduces livestock damage. On steep slopes in Pakistan, farmers participating in a reforestation program cut naturally regenerated grass under young trees and carry it to their stall-fed livestock. More fodder is produced this way than when the animals graze the hillsides. Another way to encourage stall-feeding is to provide incentives—e.g., employment of residents to plant fuel and fodder trees and tall fodder grasses on denuded common land and in eroding gullies. Stall feeding also facilitates the collection of manure for use as fertilizer.

However, stall feeding can be difficult to implement. Local constraints can develop such as increased need for labor to carry water, to harvest and transport fodder, and to clean up and spread fertilizer. Therefore, information on who does these jobs (often women) and whether they have time to take on these new tasks should be gathered before implementing such a program.

Fodder supplies can be increased by planting fodder trees or by introducing annual fodder species as a second rotation crop in permanent cropping areas. Fodder trees, pasture grasses, and legumes can be planted on embankments of terraces, on risers of terraced farmlands, near houses, and on other marginal land spots. Once vegetation is reestablished on the denuded site, controlled grazing may be allowable. However, soil compaction by livestock sometimes inhibits later natural regeneration and increases surface runoff, thus causing erosion again.

Livestock management problems in watersheds become more difficult in drier climates. Semiarid lands present the most urgent challenge. They characteristically have higher rainfall variability and greater stresses from temperature and dessication, so the land and vegetation are more prone to rapid deterioration under misuse. Creative measures must be formulated to make it profitable for livestock raisers to limit the number of livestock and to control the timing of grazing.

FARMING SYSTEMS

Damage to watersheds is most ecologically and economically significant where subsistence farmers and their livestock move onto steep uplands because they lack other alternatives. Mechanical structures and replanting programs will not be implemented adequately unless farmers and herders have incentives to invest their labor in conservation practices.

Where much of the population in a catchment area is dependent on agriculture, the most effective component of a watershed management strategy may be to increase production per unit area of land on the best sites. Other components include: agroforestry and other cropping systems that eliminate tillage or reduce it, contour plowing, timely sowing of seeds on contours, increasing crop plant density, and using improved seeds, fertilizers, and pesticides (48). On steep slopes farmers can be encouraged to plant hedges of nitrogen fixing trees or bushes on the contour, adopt mulching techniques, and interplant with legumes and pulses to reduce sheet erosion. In some places, fodder tree farming or bamboo plantations may be appropriate (39).

Some constraints to adoption of these practices are the farmers' skepticism toward new technologies, lack of capital, lack of infrastructure for effective input distribution, and lack of agricultural and forestry extension services to accelerate the diffusion of new technologies. Before new technologies are introduced, anthropological studies are needed to define the current practices, including what rewards people are getting, what shortfalls they are experiencing, and what benefits they expect from technology improvements. Both technical agents and local residents need to understand the incentives for change. Residents must be convinced that the benefits will be what they want if their cooperation is to be gained.

Inducements that can improve the quality of life for farmers living in upland watershed areas and encourage shifting cultivators to adopt more stable agriculture practices in-

Photo credit: I. A. Simpson for FAO

Medium- and long-term maintenance of tropical forest resources may depend more on sustaining lands under cultivation than it does on refining the use of the remaining forest

clude: compensatory payments to farmers excluded from upland grazing areas; timely provision of inputs such as improved seeds, fertilizer, and credit; construction of improved access roads and feeder tracks; and the provision of social services, such as improved water supplies, schools, and health clinics. Such social measures, on the other hand, can have adverse effects unless combined with rigorous exclusion of people and livestock from the steepest slopes. Improved amenities may attract larger populations into areas of critical hydrological sensitivity.

Constraints and Opportunities

Upper watersheds tend to be misused because destructive land-use systems usually give the greatest profit in the short term to the local population. The solution to this problem necessitates: 1) developing methods of land use that are more profitable to the local community and at the same time give appreciably better control of water flows, and 2) testing the new technologies and getting them adopted by the local community. New systems that minimize ecological damage will be accepted willingly only if people can see that it will maintain or increase their standard of living without an increase in the risk of crop failure.

The key issue in watershed management is not the construction of physical structures but the need to provide people with improved land-use alternatives. Therefore, a high proportion of total watershed project investment should be devoted to farming systems and institutional components rather than to soil conservation structures or infrastructure.

The additional labor and capital costs often incurred by new resource conserving systems are a major constraint to watershed management. Furthermore, farmers in the upper reaches of river systems generally do not accept responsibility for damages their land use may cause to farmers in the lower reaches. Conversely, lowland farmers rarely consider that they have a duty to help finance upland farmers to adopt better systems of land use. Watershed management projects usually have been designed to benefit people in the more fertile lowlands and have neglected those in the uplands whose lives are being affected more directly. This implies that some of the benefits gained downstream should be transferred upstream through taxes or perhaps user fees on irrigation water or hydropower.

Finally, there are several important unknowns regarding the hydrology of tropical watersheds. There is a dearth of first-hand research evidence in the Tropics documenting the quantitative relationships between various land uses and their effects on watershed hydrology (20).

The techniques for measuring and predicting tradeoffs of different management actions—e.g., grass cover versus tree cover—are not well developed. For moist climates, trees may be the best cover; for dry climates, grasses may be the best cover if fire and grazing control are practical. But for much of the Tropics, the choice is not clear. If more water rushes off grass-covered surfaces, less will be absorbed into the ground. Therefore, improved field methods for diagnosis and interpretation of watershed hydrology problems are needed to improve management decisions. The interactions of the many variables are too complex to expect neatly classified prescriptions for watershed management. Some basic measurement could be included in all major projects that lead to changes in land use in order to build a more adequate data base for predicting outcomes.

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Chapter 11

Resource Development Planning

HIGHLIGHTS

- Greater use of resource development planning could help sustain tropical forest resources. The potential application is good in tropical countries where large tracts of forest land are under the custody of the government.
- The usefulness of planning techniques can be improved by: 1) increasing the timeliness and focus of analysis, 2) improving the data base, 3) encouraging public participation, 4) adopting a more interdisciplinary approach, and 5) improving communication of findings.

RESOURCE DEVELOPMENT PLANNING TECHNOLOGIES

Most conversion of forest land to other uses occurs without adequate consideration of whether the natural and human resources available will sustain the new land use (20). The success of resource development projects is impeded by unforeseen (but foreseeable) natural resource and socioeconomic constraints. The problem is to match land development activities to the specific capabilities of the site.

Where intensive land uses are compatible with natural and human resources at a site, conversion to those uses may be sustainable and result in greater long-term benefits than keeping the land in natural forest cover. Sites that cannot sustain intensive development can be identified for reforestation or for protection of natural forest cover. These sites can be managed for watershed maintenance, nonwood products, preservation of biological diversity, outdoor recreation, or closely regulated timber harvest.

Some tropical countries have begun to use resource development planning techniques to help match land capability with land use. Resource development planning has four components: 1) biophysical assessment, 2) financial and economic analyses, 3) social assessment, and 4) monitoring and evaluation. Development planning is best viewed as a continuous, iterative process that produces information as needed rather than as a one-time, preproject activity resulting in a blueprint for development. Having a flexible project design is especially important in development projects where the risks are large and the approaches may be innovative or experimental.

Biophysical Assessment

A biophysical assessment provides one dimension of information for effective land-use management. The techniques are straightforward and relatively efficient. They can be carried out at different levels of detail with varying requirements for monetary resources, staff expertise, and available data.

Many factors affect the biophysical suitability of a site, including:

- climate—precipitation, temperature, wind, droughts, floods, storms, fire potential, and air pollution potential;
- geomorphology and geology—slopes, location and uses of surface water and aquifers, mass movements of earth, depth to bedrock, unique features;
- soils—nutrients, structure, depth, erodability; and
- flora and fauna—biological diversity, val-

uable species, ecosystem fragility, and pests and diseases.

Resource development planning techniques are most often used to select a site for a particular land use. After identification of the desired land development, the planner identifies constraints that could inhibit that land use and looks for sites where the constraints do not exist or are manageable. The other, less often applied, use of planning techniques is "land classification"—identifying the most appropriate types of development for all sites within a geographic area. Planning techniques are seldom used fully in tropical nations for either site selection or land classification (42). The latter approach has special potential as a technology to help sustain the long-term productivity of forest resources.

Land Classification

Land classification categorizes land in terms of its suitability for various uses (table 31). The objectives of land classification are to identify the resources of a given area, determine appropriate management practices for existing land uses, and predict the consequences of proposed changes in land use and policies (36).

Classifications may be at the **microlevel** for managing local parcels or at the **macrolevel** for establishing national or regional priorities. The most immediate need in developing countries is for macrolevel land classification (9,19). Microlevel analyses subsequently will be necessary (32).

In macrolevel land classification, overlay mapping techniques are often used to select

Table 31.—Common Land Classification Methods

1. ***Australian Land System.***—The Australian Land System (10) uses aerial photos to survey large areas for agricultural, forestry, and recreational potential. A "site" is defined as a uniform land form with common soil types and vegetation. A "land unit" is a collection of related sites with a particular land form. A "land system" is a group of geomorphologically and geographically associated land units, usually bounded by a geological or geomorphogenetic feature or process.
2. ***Ecological Series Classification.***—The Ecological Series Classification (37) describes forest habitat types in bioclimatic terms: a plant community's soil, water, and nutrient regimes; soil surface characteristics; and undergrowth plant distribution. The technique produces site indices for each habitat type that vary with the productive capacity of the trees, natural regeneration capability, the appropriate species for tree-planting, fertility requirements, and engineering properties.
3. ***Holdridge Life Zones System.***—Holdridge Life Zones (24) are broad bioclimatic units defined by mean annual precipitation, mean annual biotemperature (air temperatures adjusted to eliminate negative values), and potential evapotranspiration. These broad units can be subclassified by soil, seasonal rainfall distribution, drainage, and mature vegetation associations.
4. ***Canadian Biophysical System.***—The Canadian Biophysical System (30) is a hierarchical classification. The basic unit used is "land type," characterized by a homogeneous soil series and sequence of vegetation. Land types are subdivided into "land phases" according to their stage of vegetative succession. "Land systems" are groups of land types with a recurring pattern of land forms, soils, and a sequence of vegetation. The next broader unit, the "land district," has a distinct pattern of relief, geology, geomorphology, and a sequence of vegetation. Finally, there are "land regions," distinct climatic zones associated with a particular climax vegetation.
5. ***Webb's Structural Classification of Humid Forests.***—This is a classification system for humid forests based on vegetation structure and physiognomy including such factors as forest structure, composition, canopy closure, type of emergents, species growth forms, and leaf size (54). The system correlates vegetation, structure, and physiognomy with rain, altitude, cloudiness, temperatures, soils, drainage, and wildlife habitat.
6. ***Krajina's Biogeoclimatic Zonation System.***—Krajina's Biogeoclimatic Zonation System (29) is based on forest habitat types. Each zone is characterized by a climatic climax vegetation, climate, and soil type. However, "climatic climax" might be deflected into an "edaphic climax" due to poorly or excessively drained soils or a "topographic climax" on steep slopes or alluvial flats.
7. ***USDA Soil Conservation Land Capability System.***—The USDA Soil Conservation Land Capability System (28) uses soil survey mapping units grouped into eight classes according to the capability to sustain cultivation, grazing, forestry, wildlife, and recreation without erosion. The classification system indicates the degree of limitation to intensive uses.
8. ***California Soil Vegetation Survey.***—The California Forest and Range Experiment Station (5) developed a classification system predicated on the assumption that soil types are correlated with differences in vegetation on undeveloped lands. Aerial photos are used to observe the type, age, density, and structure of the vegetation.

SOURCE: Adapted from: L. Hamilton, "Land-Use Planning Technologies to Sustain Tropical Forest and Woodlands," OTA commissioned paper, 1982.

sites for particular land uses. One such technique is to produce a separate map for each of several biophysical attributes, using white, black, or shades of grey to show the suitability of locations for a specific type of development (33). The suitability ratings are combined by laying the maps over each other and examining the distribution of shading intensities. This procedure assigns an equal weight to each biophysical attribute. The "METLAND" technique (15), an extension of the map overlay approach, uses computers to manipulate data and generate alternative plans. Thus, variables can be given different weights to reflect their relative importance and more variables can be included.

Both these techniques assume natural system relationships are determined by land physiography. They are not well-suited for analyzing indirect or cumulative impacts of land uses. Unless combined with simulation modeling, these techniques do not reflect changes in the magnitudes or types of impacts over time.

Other techniques reveal site potential for specialized uses, such as the Habitat Evaluation Procedure, which assesses the impacts of land use changes on the quantity and quality of habitat for selected fish and wildlife species (51). The procedure relies on aerial photos or field work and modeling. Since a proposed action often results in gains for some species and losses for others, the Habitat Evaluation Procedure has a provision for calculating relative value weights for the indicator species.

Wadsworth's watershed value index (53) is a numerical scoring system that can be used as a rule-of-thumb in deciding where forest cover should be retained for watershed protection. The index accounts for slope and critical environmental factors.

Land classification systems can be helpful in resource development planning, but they have limitations. Some systems are oriented toward a particular land use such as agriculture or forestry and therefore tend to assess suitability for that use rather than overall land suitability (31,35,42). No single land classification system measures land productivity directly; the cost would be too great and the activity too time-consuming. Some techniques are more appropriate for use in ecological studies than for helping decisionmakers answer land management questions (6). None of the techniques identifies the direct or indirect biophysical impacts of land use conversions. Moreover, the techniques neglect gradual changes in biophysical factors that can eventually limit various land uses (31).

Applications of Land Classification

Malaysia has one of the best tropical land capability planning systems. The system includes geological surveys, regional soil surveys, and forest inventories, combining the approaches of the Canada Land Inventory and the U.S. Soil Conservation Service. It has been particularly useful in designating areas for tin mining; large-scale oil palm, rubber, and wood plantations; and resettlement projects. One reason for the effectiveness of the Malaysian system is that it is carried out by a national economic planning unit that is able to ensure that its provisions are implemented (22,34).

Resource planning techniques have been used in a number of other tropical nations, though not often as a regular planning process by a government agency or private firm in control of a large area of land. For example, the techniques have been researched and demonstrated in Venezuela (21) and Mexico (32). Organizations promoting conservation have worked out ways to integrate several of the major techniques to determine optimum locations for parks and protected areas in Venezuela and Brazil (4).

Development assistance agencies have sponsored resource development planning for river basin development programs. For example, the planning for development of the Mekong River basin, sponsored by the United Nations Development Programme, the Agency for International Development (AID), and several other bilateral agencies, uses many of the planning techniques.

AID has a number of projects involving resource development planning in tropical countries. For example, the AID-funded "Benchmark Soils Program" in Brazil, the Philippines, Indonesia, and Cameroon identifies soil types and tests similar soils for crop yields under different agricultural practices. The Government of Nepal, with AID assistance, has completed a national land inventory that includes topography, geology, vegetation, climate, and soils (1). Some land classifications have been attempted in Indonesia (45), Pakistan (43), and the Philippines (49). AID also has undertaken a major effort to help Sri Lanka plan the resettlement and watershed management associated with the Mahaweli reservoir (41).

An AID project in the Eastern Andes (the Central Selva Resource Management Project) was completely redesigned as a result of land capability analysis (23). The original project was to resettle large numbers of households for farming corn. A Holdridge Life Zone analysis involving aerial photos and field work showed that the land would support only natural forest. Consequently, the project was changed to resettle a smaller number of people who are to harvest 2 hectares of natural forest per household per year over 30 years.

Financial and Economic Analyses

After the biophysical suitability of a site has been determined, the next step is to analyze financial and economic benefits and costs. The purpose of these analyses is to provide information on: 1) how to maximize the values obtained from natural resources while conserving resources for the future, and 2) how to obtain an equitable distribution of income.

A **financial analysis** considers the anticipated cashflows to the owner or users of the land. An **economic analysis** is made from the perspective of society. The financial and economic impacts of land conversion depend on the previous land uses; capital, labor, and energy-intensiveness of the technologies; existence of markets and infrastructure; income levels; and site location, accessibility, and size. Conflicts often exist between decisions made by individuals on the basis of their own financial cash flows and the decisions that would be preferred from a societal perspective.

Financial and economic analyses can provide an additional quantitative dimension on the desirability of land-use changes and offer a systematic way to organize information for decisionmaking. Marketable goods and services are easiest to value in benefit-cost analysis. Thus, this technique is most applicable in assessing agricultural, industrial, or residential development. It is most appropriate where decisionmakers agree on values and goals (including production and the distribution of income) and where unintended effects offsite are likely.

The fundamental limitations of benefit-cost analysis are:

- imperfections that tend to distort prices observed in real markets,*
- inability to assess the distribution of costs and benefits among segments of the population and across generations,
- inadequate techniques to measure benefits or damages associated with environmental effects and insufficient empirical information on cause-effect relationships,
- de-emphasis of long-term effects due to discounting,** and
- inadequate treatment of risk and uncertainty.

Within the past 15 years, a variety of techniques used to assign value to environmental impacts for benefit-cost analysis have been developed and refined. Four basic types are:

1. **Revealed preference measures** examine actual consumer behavior and estimate prices for extramarket goods and services by examining expenditures to avert damages, replacement costs to repair damages, travel costs to recreational facilities, property values, and wage differentials;
2. **Hypothetical valuation methods** rely on direct questioning, bidding games, use-estimation games, or tradeoff analysis to

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*In many cases, estimated values ("shadow prices") must be used where market prices do not exist or are presumed to reflect societal values poorly. However, the use of estimated values can increase the potential for political manipulation of an economic analysis (55).

**Discounting is based on the time value of money—i.e., the presumption that a dollar's worth of consumption now is worth more than a dollar's worth of consumption in the future. The time preference is separate from the effects of inflation.

elicit the maximum amount that consumers are willing to pay for a gain or minimum amount of compensation that they are willing to accept for a loss;

3. **Human capital methods** are used to place values on human mortality and morbidity; and
4. **Threshold analysis** asks how large the benefits of preserving land in its current state would have to be in order to outweigh the benefits of conversion to other uses.

However, careful attention must be paid to the assumptions behind these techniques and their susceptibility to problems of validity, reliability, and biases. Many of the techniques tend to underestimate environmental values. This is not a severe problem where decisionmakers only need a minimum estimate to support conservation decisions (18), such as in cases where some preservation values clearly exceed the value of a proposed land-use conversion. For example, an analysis for the Peruvian Amazon showed that wildlife values exceeded wood product values (14). But since many situations are not so clear-cut, more sensitive techniques are needed. The most important constraint on economic evaluation of environmental benefits is not the inadequacy of the techniques but the dearth of scientific data on cause-effect relationships for various land uses (8).

Another problem arises because most economic analyses determine the environmental value of forest resources "at the margin" which can be significantly different from the average value of forest resources. For example, if the value of genetic resources in any small piece of a forest is not large, economic analyses may justify clearing the forest piece by piece until it is all converted to nonforest uses, without ever accounting for the overall loss of genetic resources (18).

Establishing monetary values for the multiple benefits of forests can be useful in making decisions on the choice of outputs, production techniques, regulatory policies, fees for concessions and leases, compensation for eminent domain or offsite damage, and priorities for industrial or social forestry projects (18). The potential users of this information include the private sector, multilateral development banks, U.N. agencies, bilateral assistance agencies, and tropical governments.

The influence economic analyses have in decisions about resource development depends on how well they address the issues important to decisionmakers. Generally, economic analyses are used to justify decisions that already have been made on other grounds (18). Furthermore, economic analyses rarely consider how benefits and costs affect distribution of income within or across generations.

Social Assessment

The social dimension increasingly is acknowledged as an essential part of resource development planning. The extent to which social assessments are carried out varies among projects and among organizations. However, such analyses can contribute greatly to the success of development projects. In the past, multilateral development banks viewed large-scale forestry operations for their economic impacts alone. The poor records of many of those projects have led to an awareness of the importance of the social and institutional dimensions of land-use decisions (39).

Some proposed development activities are not feasible because the necessary human resources are unavailable or cultural values preclude implementation. Variations in the success rates of projects often can be explained by differences in the capabilities of local institutions.* The most common problems are the: 1) lack of strong leadership accepted by the community and willing to take the initiative; 2) domination of decisionmaking by elites for their own special interests; and 3) factionalism or segmentation by socioeconomic, ethnic, or religious groups that makes it difficult to build a consensus or get people to work together (52). Government laws and policies also can have unintended effects on people's decisions to participate in projects. In particular, land tenure and commodity pricing policies are important.

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*Institutional capacity includes the framework of laws and policies in the forestry sector and the ability of national and local governments, cooperatives and associations, or private voluntary organizations to carry out a project.

A development project that involves local people is more likely to be successful if the intended beneficiaries are brought into the planning process. Otherwise, 1) the intended beneficiaries might be unwilling to participate in the project; 2) the benefits may be captured only by people with relatively high incomes, social status, and advanced educations; or 3) tasks may be planned with unrealistic assumptions about the participants' skills, capital, or access to inputs.

Culture-specific information is needed on how incentives should be structured to: 1) encourage two-way communication between technology transfer agents and local people; 2) reduce risks facing innovators (e.g., adopters of new techniques); 3) encourage activities that provide offsite benefits not captured by individuals undertaking the activities (e.g., reduced soil siltation); and 4) give landless people a stake in resource conservation. For example, one common reason why social forestry projects fail is that the local people are not interested in the species of seedlings that are distributed or are unfamiliar with their growth requirements or products (2).

Most negative impacts of reforestation or social forestry projects on communal lands fall on the previous users of the land. Little land—even that labeled uninhabited—is totally unoccupied by people. Forest reserves in most tropical countries contain farmers, hunters and gatherers, and livestock herders. Communal lands that at first glance appear to be useless scrub forests frequently are used for raising crops, grazing animals, or the collection of fuelwood, polewood, grasses, and a wide variety of nonwood products. Land tenure is particularly important to consider in a social assessment where much of the land remains untitled or under communal status because large landholders or the landless poor may have appropriated these lands.

Good social assessments can help planners avoid or mitigate some of these problems or suggest ways to compensate the people who bear negative impacts. If the interests of past users are not considered, they may undermine the success of proposed development (25).

U.S. AID conducts some social assessment for its projects (including analysis of impacts and absorptive capacity) but the amount and type are variable. There are written guidelines to prepare a "social soundness analysis" as part of each project paper (50). However, these guidelines do not provide detailed, operational guidance on ways to conduct the analysis (44).

The World Bank's *Operational Manual for Project Analysis* is being revised to incorporate social assessment procedures (39). Written guidelines have been prepared for Bank projects affecting tribal groups or involving resettlement of populations. All project officers are directed to consider social factors as part of their regular activities (16).

Monitoring and Evaluation

The preproject planning phase is when least is known about development problems to be solved and about the biophysical and human resources of the site. Yet, for many projects this has been the only time when a substantial effort is made to determine how the project's products and services will contribute to larger development goals.

Monitoring is a continuous process of collecting, measuring, recording, analyzing, and communicating information on projects regarding 1) timely and appropriate provision and use of inputs, 2) operation and management logistics, and 3) production of outputs. Monitoring takes place during implementation and is intended to meet the needs of day-to-day project management. It can indicate a need to change the timetable, scale, geographic location, resource allocation, or staffing of activities.

Evaluation measures a project's outputs and impacts on intended beneficiaries and assesses the project's unintended impacts. Evaluations emphasize performance, rather than operation and management, and analyze reasons for attaining or nonattaining objectives. Evaluations performed before implementation is completed can be used to formulate recommendations for changes in objectives, strategies, techniques, institutional arrangements, priorities, and government policies. Their effective use depends on the project's flexibility—i.e., whether it can respond to recommended changes. Such evaluations have a secondary purpose of facilitating communication among project staff, project management, local people, and external organization. Evaluations conducted after a project is complete can:

- identify a need to compensate people adversely affected by environmental impacts,
- suggest followup or complementary projects that build on the original project,
- assist in reformulating broader policies and strategies, and
- provide lessons for planning other projects elsewhere.

Monitoring and evaluation produce very different measures of project success or failure. Monitoring may indicate that a project is successfully reaching its targets, while evaluation of the same project may show that the problem has been incorrectly identified.

For example, planners working in the preproject period may identify reforestation of private lands as the appropriate objective for an area experiencing rapid deforestation and a lack of freely available seedlings as the problem hindering this reforestation. Thus, they may recommend establishing nurseries to produce seedlings for distribution to local farmers. Monitoring may show that the nurseries are operating successfully and producing the desired number of seedlings. Evaluation, on the other hand, may show that the problem was misidentified, that lack of extension programs for landowners and not seedling availability is the actual constraint to reforestation.

The distinction between monitoring and evaluation has been recognized only recently by development assistance organizations. U.S. AID and the World Bank, among others, are emphasizing the importance of both. Comprehensive monitoring and evaluation systems are a planned component of social forestry projects in Nepal (3) and Tamil Nadu in India (46). However, the development assistance agencies are only beginning to learn how to use the information from evaluation to improve projects.

Even where continuous evaluation is made a part of the project, the resulting information may not lead to a project change. One reason for this inflexibility is that persons administering resource development projects are usually rewarded when they achieve certain targets (e.g., seedlings distributed per year) from the original project plan, regardless of whether those targets prove to be unimportant. Moreover, the usefulness of final evaluations can be compromised by agencies' reluctance to discuss why their projects were not entirely successful.

Multiobjective Planning Methods

Once information is available on the likely biophysical, economic, and social/cultural aspects of a development project, decisionmakers need some way to judge the relative importance of the various findings. Too frequently, decisionmakers avoid confronting tradeoffs among conflicting objectives and only consider the most obvious and serious effects. But considerable progress has been made in the past two decades in developing multiobjective planning techniques that address these tradeoffs (12,38). These techniques have been applied mainly in water resource planning, but with adaptation they are applicable to tropical forest land-use planning as well.

Multiobjective planning is broader than more traditional single-objective approaches to planning. Single-objective planning techniques such as benefit-cost analysis require that all the effects of alternate projects be measured in terms of a single unit, usually money. Multiobjective planning attempts to compare effects within categories, but does not force all effects into the same measurement units. The techniques also provide formal means for decisionmakers to assign relative values to each category account (e.g., income, numbers of people employed, reduction in peak waterflow).

Using multiple objectives in the planning process can improve resource development in at least three ways. First, value judgments are determined by decisionmakers rather than by the analysts. Second, a wider range of alternatives usually is identified, and the relationship between alternatives can be described clearly. Third, the analyst's perceptions of a problem will be more realistic if the full range of objectives is considered (12).

CONSTRAINTS AND OPPORTUNITIES

Insufficient appreciation by decisionmakers. Many decisionmakers do not understand resource development planning techniques or their potential utility. Consequently, they may make decisions on the basis of political feasibility or intuition rather than planning (31). Resource development planning often is not used until after resource use decisions have been made. Furthermore, decisionmakers often have the misperception that planning leads to permanent land-use dedications.

Limited availability of land use data. Problems associated with collection have led to a dearth of land use data. Ground surveys are slow, expensive, and sometimes inadequate. Aerial photographs can only cover a small area and are relatively expensive. Remote-sensing images from orbiting satellites are becoming more widely used. However, with the technology generally available in tropical countries, interpretation of Landsat can be inaccurate. New optical enhancement techniques improve the quality of the Landsat images and computer analyses can increase interpretability. These refinements are expensive, but minicomputers are lowering the cost.

Governments in tropical countries have been able to purchase satellite images at low prices because the fixed, capital costs have been borne by the U.S. Government. This policy may change, however. The U.S. Government has proposed selling Landsat to the private sector.

Scarcity of expertise. Effective resource development planning requires expertise in many disciplines: geology, hydrology, climatology, ecology, geography, agronomy, forestry, economics, sociology, and planning or public administration. Even if sophisticated methods such as remote sensing and computer analyses are cost effective, the lack of trained government staff can preclude their use. The scarcity of expertise is a principal constraint to resource development planning (35).

Cost. Detailed resource development planning activities can require a high initial investment because large land areas are involved. At the same time, the benefits often are diffuse—spread among large groups of people in present and future generations rather than among a few identifiable individuals who would be willing to bear the costs. Thus, it is likely that major resource development planning efforts in poor countries will require substantial foreign assistance.

Dominance of decisionmaking by interest groups. In some countries, there is little actual governmental control over public lands because of the influence of large logging, mining, or agricultural interests and the inability to enforce sanctions in remote locations against large numbers of illegal forest occupants, nomadic grazers, or tribal groups with customary rights. Even where the government has effective control over public lands, self-interest still can be a constraint. Prerogatives over government lands often are jealously guarded by key decisionmakers (47). Forestry departments may resist any analyses that could result in land classifications that remove land from forest reserves (40). In some cases, short time horizons, personal favoritism, influence of special interests, and opportunism may characterize decisionmaking.

Increasing the timeliness and focus of analysis. An analysis will be of most use to decisionmakers if it is timely and geared to their needs. If the scope of the analysis is too narrow or superficial, decisionmakers will not obtain the information they need. On the other hand, if the scope is too broad, delays will occur. The usefulness of the techniques can be improved by clearly defining the specific objectives of the analysis and setting priorities for study. For some uses, techniques that are relatively less precise and less expensive will be satisfactory.

Improving scientific, economic, and social data. Although the basic techniques to analyze scientific, economic, and social data for resource and development planning are reasonably well-developed, the inadequacy of baseline data and the limited understanding of cause-effect relationships have hindered application of these techniques. Much existing information on the connections between biophysical factors and land uses is derived from studies of temperate zone countries (42). The degree of transferability of this information to the Tropics is questionable. It also may not be appropriate to transfer information obtained in one part of the Tropics to other parts (13).

Encouraging public participation. Inadequate social assessment is a weakness suffered by most resource development planning efforts (35). Greater public participation in the planning process could improve social assessments and increase the ability of local people to solve their own problems.

However, this can be difficult to obtain. For the most part, foresters have not been trained to facilitate a dialogue with local people to determine their needs, priorities, and resources or to convince them of the desirability of better land-use management (47). Furthermore, in some cases the rural poor do not speak openly for fear of retaliation or simply because they speak a different language from the project staff. Sometimes, individuals with vested interests can dominate participation, while the general interests of the local population are underrepresented (26). Where the rural poor are excluded from political participation in government, it is unlikely that they will be allowed to participate effectively in the design or operation of development projects (27).

Adopting an interdisciplinary approach. Many government agencies conduct activities that affect land use, especially those concerned with agriculture, forestry, military operations, water resources, mining, human settlements, transportation, and wildlife. Yet, there is little coordination between agencies with different responsibilities, and each agency concentrates on its own relatively narrow mission. Forestry departments in many tropical countries, particularly those that retain the model set up under British and French colonial rule, remain detached from other sectors of public administration (11).

But an interdisciplinary approach using the skills available in the various agencies is the most effective way to plan resource development. Alternatively, forest departments could hire expertise in a broader range of disciplines and train existing staff. Rural sociologists and anthropologists, in particular, should have a larger role in resource development planning (11). The United States offers substantial expertise in the various disciplines related to resource development planning.

Improving the communication of findings. Scientific information needs to be presented in a simple, yet realistic, form that decisionmakers can understand. Key assumptions should be stated explicitly and tested. Sufficient budget and staff time should be devoted to communication of the fundings or the plans are likely to receive little attention.

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Chapter 12

Education, Research, and Technology Transfer

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Chapter 12

Education, Research, and Technology Transfer

HIGHLIGHTS

Education

- Most education to support sustainable use of tropical forest resources must be done by tropical nations' own universities and technical schools. But these schools generally are new, small, and not yet capable of the task.
- U.S. universities can help sustain tropical forest resources both by educating professionals for work in tropical areas and by supporting the development of the tropical universities' capabilities.
- To provide adequate instruction in tropical forest issues, U.S. universities need to make fundamental curriculum changes, adding more anthropological and sociological perspectives to the education of resource development specialists.
- Environmental education programs suffer from a lack of behavioral science expertise and from a lack of literature documenting the reasons for success and failure of past programs.

Research

- Fundamental and applied research, especially in the social sciences, are needed to develop more techniques that produce sufficient profits for investors and simultaneously conserve the renewability of forest resources.
- Research on tropical forest resources is poorly coordinated. Fundamental researchers know too little about what information applied researchers need, and applied researchers know too little about the needs of technology implementors.

Technology Transfer

- Innovative technologies, even successful ones, often do not spread beyond subsidized pilot projects. Improved technology transfer efforts are needed among researchers, between researchers and project managers, and between project managers and individual decisionmakers.

INTRODUCTION

Many technical opportunities to reverse tropical forest degradation are attracting attention from development assistance organizations and from tropical government agencies. Yet, neither governments, private entrepreneurs, nor local people are investing enough capital, land, and labor on these techniques. Methods to overcome these constraints on such investment include increased professional, technical, and environmental education, some research redirection, and improved technology transfer.

Inequitable and insecure land tenure and population growth cause forest resource management problems even more basic than those addressed by forestry education, research, and technology transfer. These problems are not amenable to direct action by the U.S. Congress—they must be resolved by the tropical nations themselves.

U.S. assistance can enhance education and research, particularly in the social sciences. It also indirectly can help improve tropical nations' abilities to make fundamental changes in economic and social institutions.

EDUCATION

Professional Education and Technical Training

Progress in developing and implementing new forestry technologies is severely constrained by the scarcity of appropriately educated personnel. A severe shortage of field technicians and extension agents with suitable training further constrains implementation of existing technologies (4,18).

In the short term, an efficient mechanism for matching qualified people to the available jobs is necessary, and sufficient money and other incentives must be provided. Expatriates, including U.S. professionals, can carry out certain critical functions. However, over-reliance on expatriates is expensive, maintains dependency, may lead to adoption of inappropriate technologies, and contributes little to building a political consensus on the value of tropical forests. For these reasons and because the scope of tropical forest development problems and opportunities is so large, improvement in both the quantity and quality of education within tropical countries is essential to sustain tropical forest resources in the long run.

Forestry Education and Training Programs in Tropical Countries

Forestry degree programs are offered by 23 universities in tropical Africa, 55 in tropical Asia, and 39 in tropical America. In addition, tropical Africa has 59 technical schools offering forestry courses, tropical Asia has 118, and tropical America has 51. Nearly all of these, however, are new and produce few graduates each year.

Most of these professional and technical forestry programs have focused on commercial timber production and industrial processing. Now, however, the emphasis in tropical forest resource development is changing to include social forestry, agroforestry, and fuelwood forestry. To support this shift, the tropical forestry schools need to make some fundamental changes.

ENCOURAGE INTERDISCIPLINARY APPROACH

Professionals, including foresters, sometimes become too narrowly focused (8). This tendency is particularly troublesome in tropical forestry because the interactions between natural systems and social systems are so complex. Despite widespread agreement that the major constraints on improved forest resource management are socioeconomic and institutional, social perspectives remain underrepresented in forestry curricula.

> Forestry education has been strongly oriented toward biological sciences. It has not filled a critical need for professional understanding of and competence in determining the potential of forests in rural development; the social values in rural income and employment; reduction of urban migration; land use planning; diversification of agriculture; the linkages of the variety of products from forest resources with other sectors of the economy such as supplying raw material for low cost housing; nor with the way forest industry development can be directed to fit the various stages in the country's development (15).

Special efforts need to be taken to incorporate social science components into forestry and related program curricula. Too often, rural sociology, applied anthropology, education methodology, political science, and history are ignored. Although forest economics is included in many forestry curricula, it needs to incorporate an orientation more than industrial wood production and demand. Natural resource development planning, environmental quality assessment, and administrative and managerial skills also have been neglected. Knowledge of agronomy, soil science, range management, and animal husbandry is also important for forestry professionals in most tropical countries.

There are two ways to broaden forestry education: provide continuing education in social and agricultural sciences to forest professionals and forestry school faculty, and support the addition or joint appointments of social scientists as faculty in forestry schools. The disadvantage of the first approach is that many of these people may not have an inclination or aptitude for the social sciences. The problem with the second approach is that social scientists in tropical nations may not understand the relationship between their discipline and forestry. This can be ameliorated by providing in-house training in forestry and the natural sciences for social scientists. It would not, however, solve the problem of how to attract top quality social scientists into a field that is undersupported and generally viewed as less prestigious than other fields such as health and education.

DEVELOP TEACHING MATERIALS AND FACILITIES

Many faculty members in tropical universities were educated in developed countries. Thus, they are likely to teach concepts and use course materials appropriate for capital-intensive production forestry in temperate zones. But under tropical conditions the temperate zone forestry technologies may not be economically feasible or socially desirable. Further, temperate zone techniques can be poorly adapted to ecological conditions in the Tropics and may require equipment or skilled labor that is not available (35).

Teaching materials relevant to tropical forests are scarce. While some appropriate information and course materials are available, they are poorly distributed. This situation could improve if teachers and researchers were to receive support to develop original course materials. Teaching materials developed in tropical countries can be evaluated for their applicability in other countries. Funds could be provided to modify, translate, and distribute these materials internationally. Some surprisingly simple and inexpensive efforts can be very effective. For example, botanists have produced inexpensive and accurate tree identification handbooks by photocopying leaf, twig, flower, and seed specimens that are available in U.S. herbaria (21).

Many tropical forestry schools also lack adequate library and computer facilities, field and laboratory equipment, and arboretum or herbarium facilities. Computers, programmable calculators, and software can greatly facilitate teaching, research, and forest management. For tropical forestry schools, minicomputers are advantageous because they are relatively inexpensive and easy to operate and repair.

Museums can be teaching tools of great importance to tropical forestry. In the United States, the Smithsonian Institution, Chicago's Field Museum of Natural History, the Missouri Botanical Garden, New York Botanical Garden, and certain museums affiliated with universities are examples. Museums in tropical countries unfortunately are seldom teaching museums. They are underfinanced and not particularly useful to forestry education. Supporting development of good teaching museums with well-stocked and well-curated herbariums and arboretums would be an effective way to improve tropical forestry education (4).

RECRUIT APPROPRIATE PEOPLE

Forestry education is not a prestigious profession in most tropical countries. Careers in this field do not offer the social or financial benefits that many other fields offer. Forestry school faculties in many countries are poorly paid and many of the best quickly move on to other occupations. In some countries, teaching staff are borrowed from the Forestry Department but are selected on the basis of seniority rather than teaching ability. Consequently, forestry education is severely constrained by a shortage of qualified teachers (28) and university forestry programs have difficulty competing with other programs for funds, facilities, and top quality students and scientists.

U.S. scientists could increase their effort to help their colleagues in tropical schools gain international recognition and, thus, prestige in their universities. Development assistance agencies also could invest additional money in graduate programs for tropical forestry schools, provide continuing education opportunities for faculty, provide scholarships, sponsor research, and develop facilities (e.g., libraries, laboratories, field stations). Developing facilities alone can be a waste of foreign assistance funds, however, if expert personnel are not available or developed simultaneously (4).

DEVELOP GRADUATE PROGRAMS

Few forestry schools in the Tropics offer graduate degrees. Although the development of a strong undergraduate program is the first priority in forestry education, graduate schools are important to produce future educators, researchers, and upper-level decisionmakers. Graduate programs also are important because they involve students and faculty in modern current research. Without a research component, it is difficult for forestry and related disciplines to attract and retain top quality students and faculty.

SUPPORT TECHNICAL SCHOOL PROGRAMS

The shortage of adequately trained forestry extension agents in rural areas probably is a greater constraint on resource-sustaining technologies than the lack of professional personnel. The need for field technicians and extension workers will increase as tropical nations begin to manage forests, promote agroforestry, and disseminate improved wood-use technologies. In particular, more women should be educated as foresters, technicians, and extension agents because women are heavily involved in using forest resources and in many cultures they can be reached best by other women (20).

Recruiting students to work as forestry technicians is a problem. Few students who complete technical training take field jobs and many who do may leave them soon. Educated people generally prefer to live in urban areas, making it difficult to retain good field staff. Innovative approaches to this problem need to be developed, supported, and documented. For example, it may be useful to increase recruitment from rural areas, although this might necessitate expanding technical schools' programs to offer remedial work in basic academic skills.

U.S. forestry schools can improve technical schools in the Tropics by helping produce training materials. Also they can support education of technical school instructors through training programs organized by the Food and Agriculture Organization (FAO) or other organizations. U.S. forestry schools generally do not have the ability to contribute more directly to training technicians and extension agents for tropical forestry and agroforestry (4).

IN-SERVICE TRAINING

Even if actions to improve forestry education programs begin soon, a substantial lag will occur before those students are in influential positions. Therefore, it is also important to update training of resource management professionals and technicians.

In-service training enables staff to keep up with advances in forestry techniques and in related fields such as agriculture, livestock management, and soil and water conservation. It is particularly important for social forestry projects because conventional forestry education has included so little training on social aspects of resource development. Unfortunately, with the existing shortages of qualified professionals and technicians, it often is difficult to release forest department staff for extended training courses (40).

The United Nations FAO Forestry Department has developed a program to support in-service training of forestry personnel in developing countries. This program receives some financial support through the U.S. contribution to FAO, and this seems an effective channel for continued or increased U.S. support of in-service training. However, at present

U.S. experts play only a small part in the FAO Forestry program.

Opportunities for the U.S. in Tropical Forestry Education and Training

The United States has important expertise and experience in forestry education and has some experts in tropical forestry, botany, zoology, soils, and related topics scattered among U.S. academic institutions. These experts are contributing in a piecemeal but significant fashion to education of U.S. and tropical country foresters and other professionals interested in tropical forest resources.

In the fall of 1982, some 487 students from developing countries were enrolled at U.S. forestry schools, and a survey of 44 North American forestry schools found 33 were anticipating expansion of their international forestry activities (25). Newsletters, directories, and other networks to facilitate communication among tropical forest experts are being established, for example, by the International Society of Tropical Foresters.

IMPROVE THE CAPABILITIES OF U.S. UNIVERSITIES

Most U.S. universities have had only peripheral interests and activities in tropical forestry. This is, in part, because few U.S. faculty have experience in tropical forestry. Many of those work for State-supported universities where overseas work is not well-regarded (43). Consequently, those who seek overseas forestry work often are professionals at the beginning of their careers or those nearing retirement (4).

Few courses offered by U.S. forestry schools focus on the Tropics or on international economic and political interactions and resource interdependence (34). Some U.S. universities can give foreign students an excellent education in the fundamentals of basic science, forest management, forest industries, and quantitative methods (26). But education on the applied aspects of tropical forest management and ecology mostly is lacking. If U.S. forestry schools are to play an effective role in technology transfer to the Tropics, changes must be made in the curricula. Special attention has to be paid to the appropriateness of the technologies taught. Otherwise, students from the Tropics will not be able to apply their newly acquired knowledge. Few U.S. schools are well equipped to train U.S. or foreign students in social or community forestry.

> The training of foresters gives them a sense that they command an expertness and set of skills which permits them to diagnose and prescribe for society. Community forestry turns that upside down so that the professional becomes a coordinator and facilitator of diagnoses and prescriptions made by the community (6).

This change requires development of communications and public relations skills as well as sensitivity to cultural factors (13,30).

Lack of a tropical setting for field courses constrains U.S. universities' ability to serve the needs of students who are to work in the Tropics. Education cannot be limited to the classroom. Field courses and internships including field work are essential (38). Both the social and natural science aspects of tropical forestry involve problem-solving skills that are better learned in the field than in classroom lectures and laboratory exercises (28).

ENHANCE COMMUNICATION BETWEEN TROPICAL SCHOOLS AND U.S. INSTITUTIONS

The faculty, administrators, and students in tropical schools often find it difficult to locate particular expertise in U.S. universities. **Twinning** and **consortia** are two mechanisms that are used to facilitate communication between U.S. and tropical nation schools. Twinning refers to the establishment of a special long-term association between a forestry school in the Tropics and one in another country.

A twinning arrangement can help develop teaching and research capabilities in both institutions (4,47). It offers the advantage of continuity, providing time for faculty and administrators on both sides to understand the problems and opportunities in the other country.

It also provides the opportunity to develop good working relationships.

Twinning could be used to broaden tropical forestry education. For example, some U.S. universities have strong social science expertise that could be applied to forest resource development issues. U.S. faculty can help develop teaching materials, design or conduct research, and temporarily substitute for tropical university faculty when they are absent for course material development, advanced education, or in-service training.

Twinning, however, has disadvantages. U.S. universities are likely to perceive little benefit to themselves from participating. Thus, twinning activities may be assigned a low priority unless there is sufficient external funding (4). The exchange of faculty, students, and information may end up being one-way—from tropical country institution to developed country university. Also, since no single U.S. university offers a comprehensive program in tropical forest resources, limiting access to the expertise available in just one U.S. university could be a disadvantage to the tropical university.

Consortia of U.S. universities can resolve some of twinning's disadvantages because they can provide a wider range of expertise to the tropical institutions. The consortium can direct tropical faculty, administrators, or students to programs best suited to their needs. Some such consortia already exist (ch. 5). However, neither twinning nor consortia are able to resolve several major constraints on development of U.S. expertise in tropical forestry (4). These include:

1. Insufficient faculty competence in tropical forest resource fields.
2. Lack of tropical forest environments in which to teach tropical forest resource management.
3. Lack of a suitable setting for relevant faculty and graduate student research.
4. Lack of a center for exchange of ideas among tropical forest resource scholars.
5. Lack of a center to house necessary collateral institutions, including a tropical herbarium, tropical wood collection, and tropical arboretum.

These constraints could be overcome by designating and developing institutions, located in U.S. humid tropical and semiarid areas, to serve as **centers of excellence** in tropical forest resource development. The primary purpose of such centers would be to advance tropical forest resource education. They also could conduct research programs and act as information clearinghouses. For these centers, tropical forest resources would not be a peripheral interest; they would be the main focus. And because the research and teaching could be applied to resource development in the area where the centers are located, they should receive support from State and territorial organizations.

If emphasis on the special importance of social sciences, economic botany, and other disciplines were written into the charters of such centers, they could become more truly interdisciplinary than are conventional forestry schools. It would be difficult to assign permanently at one location the breadth of expertise necessary for an excellent program on tropical forest resources. This could be accomplished by using a core staff of research scientists together with a series of short-term assignments of faculty from various institutions (4).

The information clearinghouse function of the centers of excellence could serve not only education organizations but also resource development agencies in tropical nations. The centers could identify:

- appropriate U.S. organizations where people from tropical countries could obtain graduate and post-graduate training,
- U.S. organizations where tropical universities can find institution-building expertise,
- tropical organizations interested in collaborative research and instruction with U.S. universities,
- sources of funding available for these exchanges, and
- expertise on various new or existing technologies.

The U.S. Forest Service has a program providing such information for AID projects. Evaluations indicate that the quality of AID's forestry-related projects has been substantially improved by this relatively inexpensive effort. Centers of excellence could extend this broker function to institutions other than AID.

Locating the centers of excellence in the United States would help assure continuity and stability of funding, thus giving better opportunity for long-term research, training, and service capabilities (4). Associating such centers with existing institutions could avoid the costs and risks of establishing entirely new facilities. For example, the U.S. Forest Service Institutes in Puerto Rico and Hawaii could be developed as centers of excellence to serve tropical America and tropical Asia, respectively. Similarly, the Kleberg Wildlife Research Institute in Kingsville, Tex., which conducts some research and training in semiarid land forestry, could be strengthened and broadened to become a center of excellence.

A major drawback to the center of excellence concept is that substantial Federal funding might be necessary. Another disadvantage is that the U.S. tropical island locations are not biologically typical of forest resources on tropical continents, and none of the U.S. locations have sociological or institutional conditions similar to tropical nations. The centers might overcome these constraints by arranging to use facilities at tropical universities as field stations or by helping tropical schools develop new field stations.

An alternative to establishing new centers would be for the United States to offer support to international institutions that are working to provide tropical forest resource education and research programs, such as the International Council for Research on Agroforestry (ICRAF) located in Kenya, the United Nations University (UNU) headquartered in Japan, and the Centro Agronómico Tropical de Investigación y Enseñanza (CATIE) in Costa Rica. These institutions have cooperative programs with universities in other tropical countries. Concentrating the U.S. effort on existing international institutions would not be a complete substitute for a U.S. center of excellence, however. The forestry mandates of these institutions are relatively narrow—their forestry efforts focus mainly on agroforestry and, except for ICRAF, their major emphasis is on annual crop agriculture.

Environmental Education

One reason why the forestry sector has been relatively neglected in many tropical countries is that decisionmakers and the general public are unaware of the costs of forest degradation and the benefits of forest maintenance. Environmental education is a term that covers a broad range of efforts to change people's behavior by 1) giving them knowledge regarding interactions between natural resources and the quality of their lives, 2) inspiring an emotional commitment to environmental quality, and 3) teaching what actions individuals and groups can take to sustain or improve the productivity of their environment.

To change people's attitudes toward natural resources, an education program should be based not only on technical knowledge of environmental sciences but also on knowledge of the psychological and cultural factors that motivate human behavior (39). However, environmental educators are generally not trained in the sciences of human behavior and so do not apply the scientific method to improve environmental education techniques. Trial and error with little basis in scientific theory can lead to improvements if the reasons for success and failure are documented. Unfortunately, environmental education programs in tropical nations, perhaps because they are so small relative to the problems they address, seldom set aside sufficient funds or time for evaluation and documentation (45).

Ideally, environmental education should be incorporated into regular curricula at the primary school level. That is when basic attitudes and values are formed, and primary school will be many tropical people's only formal education. Practical considerations, however, constrain this broad and future-oriented approach. The few environmental education programs that exist are poorly funded and understaffed. Thus, priorities must be set to ensure the effective use of very limited educational resources. For U.S.-funded efforts, the most effective approach may be to focus first on those who make decisions of greater long-term impact—politicians, government officials, and faculty who are teaching potential future leaders.

Mass media can provide effective means to reach populations outside the classroom. They can be used to teach principles of ecology and resource management, to illuminate pressing resource development problems, and to explain how people can affect resource sustainability directly or by influencing public policy. Radio, newspapers, pamphlets, and comic books have been cost-effective tools for education in tropical countries. Environmental education activities also can be tied into development projects in their public outreach and monitoring and evaluation functions (36).

Principles of Environmental Education

The state of the art in environmental education is not sufficiently advanced to predict specifically what techniques will succeed in various situations. But a review of development assistance programs with environmental education components has indicated general principles for success in environmental education (45). Programs should:

- address specific resource problems,
- reach particular audiences,
- reach all the decisionmakers who must participate in the solution to the problem,
- be compatible with cultural values and personal motivations,
- include opportunities for continuing evaluation, documentation, and adaptation, and
- include opportunities and support to make the education effort ongoing and capable of spreading to other audiences. (45).

The environmental education task is straightforward only where benefits accrue directly to the decisionmaker. For example, a social forestry project in Northern Pakistan that seeks to change the use of steep deforested hillsides has had enthusiastic participation from farmers who want to preserve their land's productivity for the benefit of their children. However, getting government officials to allocate scarce resources to expand the program has not been so easy. The program benefits some upland farmers in a few years and more downstream farmers in many years, but it may never directly benefit the government personnel by bringing political recognition.

Another example that demonstrates several of the environmental education principles is a Peace Corps project in Paraguay that trained rural elementary school teachers in basic environmental education methods. The program was designed to include the faculty and staff from the schools, officials from the Ministries of Agriculture and Education, and Peace Corps staff. Ministry officials were convinced of the importance of environmental education through workshops and discussions. To encourage the teachers, the Ministries agreed to provide salary increases for teachers in a pilot program who developed and evaluated an environmental education curriculum for their students. However, the importance of a multilevel approach became apparent when the Peace Corps diminished its involvement with ministry officials and focused only on the teachers. Ministry support declined and so the teachers could not spread the curriculum they had designed beyond the initial pilot project area. This suggests that the program may have failed to provide for the personal motivations of all levels of decisionmakers who would affect the program's success.

Because changes in human attitudes are difficult to effect and measure, environmental education efforts will remain difficult to evaluate, document, and duplicate. This gives the technology a disadvantage when competing with other, better developed technologies that have more easily measured results. Although environmental education lacks a strong basis in behavioral science, it can still progress if programs are documented by the practitioners.

RESEARCH

Fundamental and Applied Research

Sustaining tropical forest resources depends on implementing technologies that simultaneously can: 1) provide basic needs (food, fiber, fuel, construction materials, and cash), 2) sustain the renewability of the resources, and 3) be profitable and culturally acceptable to different groups with different levels of knowledge, skills, and resources. Technologies that meet all these requirements exist for only a few tropical forest situations, but probably could be developed for other kinds of forests with other socioeconomic conditions. Such technology development will require fundamental research on both natural and manipulated ecosystems, applied research on technologies appropriate for specific cultural and ecological conditions, projects implementing the technologies, and evaluation research that leads to continuous improvement and diffusion.

Photo credit: U.N. Food and Agriculture Organization

Forestry research, both fundamental and applied, is often poorly linked to development programs. However, programs exist that can pay substantial returns on the research investment. Here a Teca tree is prepared for transplanting at the Magdalena Valley Corporation's research center at Santa Marta, Colombia

The purpose of **fundamental forestry research** is to increase understanding of the structure and functioning of forest ecosystems, the physiology of plants and animals, and their use by humans (33). This work serves as the foundation for the principles and techniques used in **applied forestry research,** which is directed toward solving particular problems or improving the use and conservation of forest resources (9). In practice, the distinction between fundamental and applied research often is difficult to make.

Fundamental and applied research on forest resource systems typically require long periods of study before firm conclusions can be drawn because:

- tree lifecycles are long,
- tropical forest components have complex interactions,
- some of these interactions manifest slowly as cycles of plant succession and climate occur, and
- interactions can be obscured by changes in weather and hydrologic flows,

Longer terms for research funding (4-5 year budgets) generally result in better research and, in the long run, more efficient use of research funds (12,33).

Moreover, applied forestry research usually must be site-specific, and transferring the results to other locations often necessitates repeating some of the research. Ecological and silvicultural research in natural forest management, soils, pests and diseases, watershed management, and wildlife are especially site-specific (9). Sociological research similarly is area-specific because of differences in cultures and local problems (20). Site-specificity, however, can be overemphasized. Well-designed applied research can produce general lessons that can be extrapolated and can accelerate research at other sites (12,46).

Research Priorities

Fundamental Research

Fundamental research on tropical forests has concentrated more on evolutionary biology than on tropical ecosystem processes (12). Much research seems simply to reaffirm what has been known for decades. Recognition that the moist tropical forest exists essentially in balance with its environment by recycling nutrients obtained from decaying plant material, not by drawing upon soil minerals, was recognized in 1937 (17). The relationship of chemistry and mineralogy to the hardening of certain soils in the hot, wet Tropics after forest clearing was described in 1956 (2). And because it was recognized that soils of the hot, wet Tropics largely were devoid of important plant nutrients, the overlying forest cover was described as early as 1958 as being ecologically "a desert covered by trees" (10).

Scientists have begun to recognize the need to shift research emphasis to include human manipulation of the ecosystems. The National Academy of Sciences Committee on Research Priorities in Tropical Biology has concluded that tropical ecosystem studies should concentrate on areas that are "selected because they are representative, diverse, and capable of experimental manipulation and because of scientific and societal importance."

The NAS report calls for in-depth study of four types of tropical ecosystems: infertile new world moist lowland forest, fertile new world moist lowland forest, Southeast Asian lowland forest, and new world deciduous forest. The report does not say what technique was used to calculate tradeoffs in choosing these four types. The semiarid open canopy forests and shrublands of the Tropics are poorly represented in the ranking, which suggests that the scientists on the NAS committee give higher priority to the goals related to biologically "rich" environments than to environments where the effects of resource degradation on humans are most immediate.

Regarding priorities for biological inventory, the NAS committee cites areas that contain the richest and most highly endemic biota and those containing biota in immediate danger of extinction. This includes the coastal forests of Ecuador, coastal southern Bahia and Espirito Santo in Brazil, the eastern and southern Brazilian Amazon, western and southern Cameroon and adjacent parts of Nigeria and Gabon, Hawaii, Madagascar, Sri Lanka, Borneo, Celebes, New Caledonia, and forested areas in Tanzania and Kenya.

The committee assigned highest priority to anthropological studies and to interdisciplinary rsearch on the historical, political, social, and economic phenomena that lead to ecological instability in the Tropics. In Mexico, Indonesia, and Thailand, ecological and anthropological research are being combined to investigate traditional resource use systems (16). This approach seems especially likely to lead to modern techniques that are at once profitable and resource conserving (16).

Applied Research

A common criticism of applied forestry research is that it is not focused on resource management needs. Many forest research institutes in developing countries study highly specialized topics to serve academic purposes (27). The management-oriented research that occurs has emphasized short-term trials of exotic species and specialized plantation techniques (5). Often research is based on outdated methods or is implemented incorrectly (22). Furthermore, most of the applied research in tropical forestry has been restricted to biophysical topics while many, perhaps most, of the real constraints are social, economic, or political (23,27).

Applied forest resources research can be made more relevant if the researchers understand the problems faced by technology implementors. Government project managers, extension agents, timber concessionaires, forest industry managers, users of nonindustrial private forests, and other potential users of research findings should help select the research topics (24).

An exchange of information with local people also is usually necessary to correctly identify resource development problems. Yet, processes to allocate research funds usually involve little interaction with local people until after the topic is set (20). Researchers need to increase their sensitivity to what is achievable in situations where capital and management skills are scarce and where labor is abundant but costly (14).

Before 1980, few systematic attempts had been made to establish comprehensive priorities for applied tropical forest research or to coordinate programs. Since then, various organizations have recognized that the limited research funds must be used more efficiently and have produced priority lists. Tables 32, 33, and 34 show priorities identified by the

Table 32.—U.S. Priorities for Applied Research

I. Reforestation and afforestation
  A. Species selection
  B. Erosion control
  C. Maintenance of soil fertility
  D. Nursery establishment and planting techniques
  E. Protection
    1. Grazing animals
    2. Pests and disease
    3. Fire
  F. Shelterbelt configurations

II. Meeting the demand for fuels
  A. Alternatives to fuelwood
  B. More efficient, culturally acceptable woodstoves and charcoal production techniques

III. Industrial forestry and conservation
  A. Properties of species currently not used by industry
  B. Techniques for decreasing wood losses in harvesting, transport, storage, and processing

IV. Remote sensing applications

V. Integration of forest management into comprehensive rural development
  A. Multiple-use management
  B. Combinations of activities
  C. Incentives for carrying out sound management

VI. Economics
  A. Relationship between forest land management and watersheds
  B. Value of wildlife
  C. Relative merits of village woodlots, farm forestry, reforestation, agroforestry, and strip planting
  D. Demonstration effects of forestry programs

SOURCE: U.S. Interagency Task Force in Tropical Forests, *The World's Tropical Forests: A Policy Strategy and Program for the United States* (Washington, D.C.: U.S. Government Printing Office, 1980).

Table 33.—World Bank/FAO Priorities for Forestry Research in Developing Countries

I. Forestry in relation to agriculture and rural development
  A. Sociological and institutional research
  B. Farming systems using trees
  C. Watersheds (catchments) and range management
  D. Wildlife in relation to rural welfare

II. Forestry in relation to energy production and use
  A. Silviculture of biomass/fuelwood species and systems
  B. Yield, harvesting, and properties
  C. Industrial research related to village technology
  D. Comparison with alternative fuels (social, technical, and economic efficiency)
  E. Wood-based derivatives

III. Management and conservation of existing resources (mainly natural forests)
  A. Resource survey
  B. Conservation
  C. Silvicultural systems for natural forests
  D. Whole tree use
  E. Use and marketing of secondary species
  F. Wood preservation

IV. Industrial forestry
  A. Silviculture and management
  B. Wood properties

SOURCE: World Bank/Food and Agriculture Organization, *Forestry Needs in Developing Countries: Time for a Reappraisal?* paper for 17th IUFRO Congress, Kyoto, Japan, Sept. 6-17, 1981.

Table 34.—The East-West Center's Priority List for Scientific Forestry Research

Rank	Subject
1	Ecology
2	Silviculture
3	Agroforestry
4	Reforestation, afforestation
5	Watershed management, hydrology
6	Fuel, bioenergy
7	Forest industries and use
8	Surveys and inventories
9	Education, research, and training
10	Policy and planning
11	Logging and transport
12	Nursery practice
13	Genetics
14	Marketing
15	Economics, especially of product processing
16	Land tenure
17	Soils
18	Protection of wood products
19	Forest products (technological)

SOURCE: E. Brunig, *Summary Report on the Asia-Pacific Regional Workshop for Forest Research Directors* (Honolulu, Hawaii, East-West Center Environment and Policy Institute, 1982).

U.S. Interagency Task Force (43), The World Bank/FAO (47), and the East-West Center Conference (5).

The recent creation of research priority lists suggests that organizations funding applied tropical forestry research may begin to exert more control over which topics are investigated. Other recent developments suggest that the scientists who do forestry research are recognizing the urgency of tropical forest resource problems and are ready to cooperate with coordination efforts.

For example, the International Union of Forestry Research Organizations (IUFRO) has concentrated on timber production for use in the industrialized nations. Now, it is shifting its focus to forestry in the developing nations and is organizing a series of international workshops on fuelwood systems and multipurpose trees for reforestation of degraded lands. These workshops are expected to guide research funding by donor agencies such as AID. Meanwhile, AID is substantially increasing its funding for forestry research over the next 10 years.

Dissemination of Research Findings

Within many tropical countries, little communication takes place between research organizations and the government agencies that carry out resource development programs (47). In some countries, language barriers and the scarcity and cost of translation services cause difficulties. However, even within the United States a similar lack of communication occurs between forestry researchers and technology implementors (9). Researchers are not rewarded for publishing in popular literature, and the planners and managers of forest resource development projects seldom have the time or inclination to study technical reports in scientific journals.

Obstacles to effective dissemination include:

- lack of public recognition of the relevance and urgency of the situation,
- lack of political support,
- unwillingness to accept risks,
- inadequate verification and demonstration of findings,
- incompatibility between donor objectives and research needs,
- failure to use the potential of the popular media,
- inadequate funding of dissemination activities,
- incomprehensibility of dissemination presentations, and
- insufficient experience in dissemination (5).

Dissemination of research findings to decisionmakers and field staff could be improved with better organization and funding (27). IUFRO carries out some dissemination, but its role could be increased. IUFRO's official publications are issued in English, French, and German; the lack of Spanish translations is a deficiency. More study tours and exchanges among developing countries could increase technical cooperation (47).

Computerized information storage and retrieval systems exist in the United States and in other industrial nations that could be used to improve the dissemination of research results and, thus, could greatly enhance the benefits derived from research on tropical forest resources. Examples include the AGRICOLA bibliographic systems of USDA's National Library of Agriculture, Ecosystematics and other data bases at USDA's Economic Botany Laboratory, the Smithsonian Science Information Exchange, the U.S. Forest Service Current Information System, and the Commonwealth Forestry Institute System (Oxford, England).

The U.S. Forest Service has a popular periodical, *Treeplanter's Notes,* that disseminates research findings to forestry practitioners. The FAO Forestry Department does have a publication, *Unasylva,* but it has a broad focus and is aimed at government decisionmakers in the forestry sector, so it seldom gives the detail forestry practitioners need. Field-level managers need regional publications that are not overly technical (23). The U.S. Forest Service filled this role in one region with *The Carib-*

bean Forester until this publication was terminated in 1963.

AID supports a large number of small newsletters but these are not always well-publicized and most of them have a narrow focus (23). One effective newsletter published by AID, *Resources Report*, reviews technical reports and will send copies to less-developed-country subscribers who request them. More efforts also should be made to translate key research findings into local languages.

Summary

A number of institutional weaknesses in developing countries contribute to the inadequacy of forestry research. The most serious deficiency in many countries is the shortage of qualified scientists. Researchers often lack scientific skills as well as related skills in research management and administration, technical writing, research design and analysis, foreign language, and data processing (5). Mechanisms exist to provide in-service training to tropical nation scientists at universities and herbaria in the United States, and at the research stations of the Forest Service and other agencies of the Departments of Agriculture and Interior. A thorough review of such opportunities by the General Accounting Office or a similar agency might reveal ways to use them more effectively.

Well-qualified scientists in tropical nations often leave government service or emigrate abroad because of low pay and recognition; inadequate funding; limited research facilities, equipment, and libraries; or the shortage of suitable colleagues. Research is hindered in some countries by bureaucratic rigidities, overcentralization or fragmentation, lack of political support, and interagency rivalries (9,22,33). In many tropical cultures, little prestige is attached to forestry research because the educated, urban class views field work in rural areas as hardship duty appropriate only for lower level staff (22). U.S. scientists concerned about the degradation of tropical resources could act through their various professional organizations to enhance the prestige of their colleagues in tropical nations.

Although the United States has recognized strengths in the social sciences, the number of U.S. social scientists with expertise relevant to tropical forest resource development is not known. They may constitute one of the major U.S. academic strengths for research on technologies to sustain tropical forest resources. One or more centers of excellence in tropical forestry, as discussed earlier in this chapter, could serve to better coordinate the scattered U.S. research expertise.

TECHNOLOGY TRANSFER

Background

The experience of U.S. forestry organizations shows that many potentially profitable techniques languish for lack of effective technology transfer among scientists and between scientists and technology users (9). The tropical nations facing severe deforestation and rapid population growth cannot afford such inefficiency. Therefore, a concerted effort is needed to build local organizations' capacities to choose, receive, adapt, and deliver technologies appropriate to local circumstances.

Technology transfer is the business of the development assistance agencies, and the way in which they conduct their business has a major influence on whether renewable resources are kept renewable. The literature on technology transfer is voluminous but mainly theoretical, and little of this theory is focused on forest-related technologies. So OTA convened an interdisciplinary panel to consider the conditions necessary for successful transfer of tropical forest resource technologies.

Necessary Conditions for Successful Technology Transfer

Nine key conditions for successful technology transfer were identified. **First,** the technology should be adapted to the local biophysical and socioeconomic environment of the users. The technology to be transferred should have been used successfully elsewhere under similar conditions, at least on a pilot scale. Technology transfer should not be confused with experimentation or applied research. Otherwise, the technology is likely to be unsuccessful and the adopters might become unwilling to try other innovations.

Second, technology is transferred most effectively by direct people-to-people actions. People who are to adapt and apply the technology need to learn it directly from people who have experience applying it. Successful technology transfers seldom are based solely on media presentations, such as pamphlets, books, radio programs, or films. Rather, personal interactions are essential. Media presentations, however, can help motivate the personal interaction, supplement technology transfer efforts, and support subsequent applications of the technology (3).

Third, the technology transfer agents must be well-qualified and able to communicate effectively to people who are capable of receiving and applying the technology. Agency personnel who are themselves learning the technology for the first time as they try to transfer it are often a cause of failure. Thus, development assistance agencies need to employ substantial numbers of experienced technical personnel.

A more significant constraint is the lack of indigenous capacity to continue the technology transfer beyond the boundaries of development assistance projects. Thus, the task for development assistance agencies is to enable local organizations to build an effective system of transfer agents who use personal contact to reassure people about the appropriateness of an innovation and who provide the information needed for a fair trial.

Fourth, in addition to transfer agents and capable recipients, "facilitators" or "middlemen" are needed. These people must understand the technology transfer process, especially the market for the technology and its products and the political, social, and economic constraints and opportunities affecting the other actors. Because technology transfer is usually a long-term process, subject to mistakes and setbacks, it needs advocates to help the new technologies compete with established ways of using resources. Thus, facilitators must maintain their roles throughout the transfer process.

The permanent staff of development assistance agencies could act as facilitators. Too often, however, they are rotated to other parts of the agency before the technology transfer process is complete. An alternative is for the development assistance agencies to locate and work with facilitators among the indigenous tropical people (31).

Fifth, users and transfer agents should be involved in choosing, planning, and implementing the technology transfer so it meets actual needs and is appropriate for the situation. For example, women are most directly affected by community forestry projects but are usually excluded from problem identification and project planning efforts (1).

Sixth, all parties involved must feel that they are "winners" and must, in fact, be winners. Each actor's interests should be identified at the start of the technology transfer process so they can be addressed. Early in the transfer process, the potential users must be shown the merits of an innovation (31). Many ideas that outsiders think will solve development problems may not seem so beneficial to the people who are directly affected by them. For example, village woodlots may be supported by local women who otherwise must walk far to collect each day's fuel but resisted by local men who may view them as an unprofitable use of land and by herders who may view them as an intrusion on grazing land.

For technologies designed to produce items or services for sale, the intended adopters usually must have information on markets in order to anticipate benefits. With reforestation or forest product technologies, the information can be obtained through demonstration projects, surveys, and market research. Where education and research technologies are being transferred, it is necessary to determine who will reward the educator or researcher for using the new technologies.

Seventh, the participants must be aware of subsequent steps in the transfer process and the relationship between their actions and those steps. This requires early definition and communication of roles for each person involved. A well articulated strategy must be devised. Of course, this strategy must be flexible, since it is planned at the time in the transfer process when least is known about how it will work. In particular, plans must be made to disseminate the technology beyond the pilot project.

Eighth, demonstrations of the technology should take place under conditions similar to conditions that will exist subsequently. Pilot projects should not be made unrealistically easy by being given unrealistic levels of funds or other inputs, being located where there are few socioeconomic or institutional constraints, or being provided with artificial markets.

Finally, the initial commitment of resources should be sufficient to carry the technology transfer until it is self-supporting. A transfer is self-supporting when the techniques have been adapted to local conditions and are being adopted spontaneously by organizations or individuals.

Opportunities to Improve Technology Transfer

In agriculture, development assistance agencies have had impressive technology transfer successes. Yet, relatively little has been done in the forestry sector. The need for international assistance in development of forest resources has been realized only recently, but there are already some indications that the level of such assistance is leveling off (29). The assistance agencies' major opportunities, then, lie more in increasing the likelihood of technology transfer success than in increasing the number of projects.

Coordination of Development Assistance Agencies

Many organizations attempt to help tropical nations develop forest resources, but these efforts are poorly coordinated. The causes of tropical forest degradation are so complex that no single assistance agency is likely to be able to create sufficient conditions for the forests to be sustained. To do that the various capabilities of all the development assistance agencies are needed. However, it is unlikely that these capabilities will be applied at the right places at the right times simply by chance.

The need for improved coordination was stressed in the report of the U.S. Interagency Task Force on Tropical Forests. In section 118 of the Foreign Assistance Act, Congress has given AID a specific mandate to improve coordination of forestry and natural resource development assistance in tropical nations. But the needed coordination does not occur because of the structure, staffing, and management of development assistance bureaucracies. In the tropical countries, these organizations are generally too understaffed to manage their own programs sensitively and have no incentives to coordinate and collaborate with others (42).

In theory, long range strategies and coordination should be administered by agencies of the tropical nations. In practice, when funding is from foreign or international donor agencies, decisions to implement projects are often made without reference to a long-term resource development strategy or to how the project compares with alternative investments. Because the availability of the donor funds usually cannot be separated from a specific project (41), the immediate need to maximize foreign donor funding interferes with the longer term need to coordinate donor efforts.

One way to get around these bureaucratic constraints is to establish ad hoc international organizations with no programs or policies to promote other than 1) design of long-term strategies for technology transfer to effect sustainable resource development, and 2) coordination of assistance agencies' contributions to carrying out those strategies. Coordinated Development in Africa (CDA) is such an ad hoc organization that seems to be gaining the political influence and the technical expertise necessary to make this approach work. Its efforts are directed to designing long-term strategies. Whether the coordination necessary to follow such strategies will be politically feasible remains to be demonstrated.

Need for Professionals

Another major constraint on successful technology transfer is misidentification of resource development problems. This results from a lack of public participation in planning technology transfers and from a too-narrow technical approach to project planning (19). While the need for participant planning and interdisciplinary technical inputs is widely recognized, it is too seldom realized. To a large extent this is because of the shortage of technically experienced personnel in development assistance agencies' offices in the tropical countries (42).

Chronic understaffing means that people in charge must spend nearly all their time doing bureaucratic functions. Technical inputs are then left almost entirely to contractors. This means the agency staff must make decisions about technical matters which they are often not qualified to decide.

One opportunity to overcome the shortage of professionals is to encourage experts who work for U.S. Federal agencies to take temporary assignments in development assistance agencies (44). This probably cannot be done effectively without increasing some budgets, however. Supporting U.S. nationals overseas is more expensive than supporting them domestically, and their absence would disrupt the programs of their regular agencies. Public Law 85-795 enables domestic agencies to assign personnel to international development organizations, but it is seldom used.

Technology Transfer Timing and Followup

Technology transfer, especially where the emphasis is on building the capacity of local institutions to select, adapt, apply, and disseminate technical innovations, is a long-term process. Periods of 10 to 20 years are typically needed before progress can be measured in terms of product or income. Yet, short development project planning and funding cycles often mean that projects must be evaluated at the end of 2 to 5 years to determine whether funding is to continue. At this stage, a technology transfer project is barely under way and should be expected to have revealed problems and be experiencing setbacks. Thus, the function of an evaluation should be to develop information on how to deal with these. However, this important function is compromised if participants in the evaluation fear that a seemingly negative evaluation will lead to premature termination (42).

Once a technology transfer appears to have become self supporting on a local level, continuing technical support is often necessary. Unforeseen problems will arise during the technology's diffusion, and these may be beyond the technical capacity of the local institutions. Regional centers of technical expertise that offer continuing education to technicians, technology managers, and technology transfer facilitators, and that disseminate further innovations and improvements in technologies, could help solve this problem. This has proven successful with remote-sensing technology transfer projects sponsored by development assistance agencies in Africa (7).

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Chapter 13

Forestry Technologies for U.S. Tropical Territories

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Chapter 13

Forestry Technologies for U.S. Tropical Territories

HIGHLIGHTS

- The potential of forestry to contribute to economic development has been underestimated in the U.S. tropical territories.
- Although large-scale industrial forestry is not practical in the island territories, many other technologies exist that can help satisfy the needs of growing populations and sustain the forest resources.
- Implementation of suitable technologies will rely on developing skilled personnel within these regions and on raising decisionmaker and general public awareness of forest resource potentials.
- Until local natural resource agencies have adequate staff and funding, Federal assistance will be required. Without this, needed resource productivity and development opportunities will be lost.

FORESTRY IN THE U.S. TROPICS

Until recently the forests in the U.S. tropical territories have not been managed actively. In fact, while overexploitation is not now a problem in most areas, poor land uses in the past have left the islands with significant amounts of abandoned agricultural land and relatively unproductive secondary forests.

The U.S. tropical territories also are characterized by growing populations, rising imports of food, fuel, and wood, dependence on Federal income supports, and generally high unemployment. Unemployment in Puerto Rico, for example, exceeds 20 percent in general and approaches 35 percent in rural areas (19). Development of appropriate forestry and agroforestry technologies could help alleviate some of these problems. Such technologies could provide local substitutes for imported products, providing employment and income opportunities, and protecting against erosion, floods, and similar environmental damage.

The following discussion of technologies that offer opportunities for sustainable development of forest resources in the U.S. tropical territories is organized in parallel with chapters 7 through 10. It deals with conservation of undisturbed forests, reducing overcutting, managing disturbed forests, and forest technologies to support agriculture. Two other sections, corresponding to chapters 11 and 12, discuss technologies for resource development planning, professional and technical training, environmental education, research, and technology transfer.

TECHNOLOGIES

Technologies for Undisturbed Forests

Few truly undisturbed forests exist in the U.S. Caribbean and western Pacific territories. Those remaining after the past century's history of deforestation for agriculture are mostly in inaccessible regions. There are, however, considerable acreages of secondary forest, some old enough to fit this report's definition of undisturbed forest.* Two methods are available to sustain these forest resources: 1) preserve samples of forest ecosystems in parks and protected areas, and 2) make undisturbed forests more valuable by increasing sustainable production of marketable nonwood products (ch. 7).

Sample Ecosystems

Protected forest areas are well-established in Puerto Rico and the U.S. Virgin Islands, but few have been created in the western Pacific. The most valuable areas of primary forest and the remaining rare and endemic tree species are protected in Puerto Rico in the National and Commonwealth Forest reserves and in the U.S. Virgin Islands National Park. That park covers nearly three-quarters of St. John Island. The Caribbean National Forest in Puerto Rico was established in 1903 and now encompasses 28,000 acres of rain forest. The first Commonwealth forest reserves were formed in 1918. Now 13 of these cover 59,000 acres and they include moist and dry forests and mangroves (fig. 32). Protection policies for these areas have been fairly effective and remain strongly supported.

In 1976, the Caribbean National Forest** was designated a biosphere reserve under the UNESCO Man and the Biosphere (MAB) program. This program is designed to protect representative samples of major ecosystems and to promote ecologically sound land-use practices in adjacent areas. The forest was subsequently divided into a central zone where no recreation or management activities are allowed, surrounded by a recreation zone that attracts hundreds of thousands of visitors each

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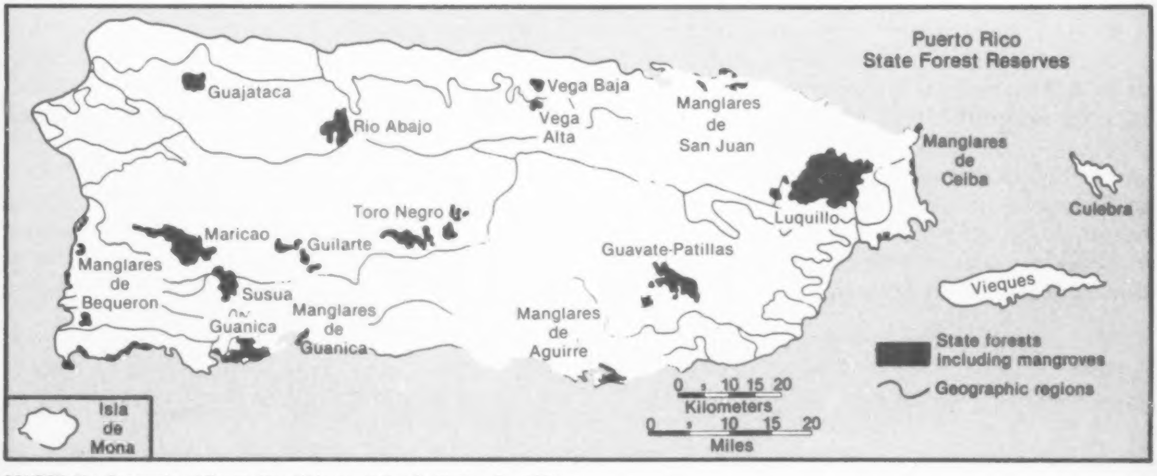
*Undisturbed tropical forests are areas where trees are the dominant woody vegetation covering at least 10 percent of the ground and where trees have not been cut during the past 60 years.

**The Caribbean National Forest also is known as the Luquillo Experimental Forest and the Luquillo Biosphere Reserve.

Figure 32.—Puerto Rico Commonwealth Forests


Puerto Rico
State Forest Reserves
Guajataca
Rio Abajo
Vega Baja
Vega Alta
Manglares de San Juan
Manglares de Celba
Culebra
Luquillo
Toro Negro
Maricao
Guilarte
Guavate-Patillas
Manglares de Bequeron
Susua
Guanica
Manglares de Guanica
Manglares de Aguirre
Vieques
State forests including mangroves
Geographic regions
0 5 10 15 20
Kilometers
0 5 10 15 20
Miles
Isla de Mona

SOURCE: *The Geography of Puerto Rico* (Chicago: Aldine Publishing Co., 1974).

year, and an outer zone where the U.S. Forest Service Institute of Tropical Forestry conducts forest management research. Part of the Virgin Islands National Park (11,000 acres) and Puerto Rico's Guanica State Forest (10,000 acres) also have been designated MAB biosphere reserves (10).

Creation of a protected area system has been considered in the Pacific Islands for some time, but little has been done. In 1956, the High Commissioner of the Trust Territory of the Pacific Islands established the Ngerukewid Islands Wildlife Preserve (the Seventy Islands Preserve) in the Limestone Islands of Palau (11). This includes war sites and sites where the Yapese people carved wheel-shaped stone money that reaches up to 8 feet in diameter. This preserve also protects the endangered Micronesian megapode, the dugong, and other threatened plant and animal species.

The U.S. National Park Service administers the War in the Pacific National Historical Park on Guam, which is forest-covered. The U.S. Forest Service helped the Guam Department of Agriculture establish the Patti Point Natural Area on Andersen Air Force Base. In 1973, the U.S. Fish and Wildlife Service created the Rose Atoll National Wildlife Refuge at the request of the government of American Samoa. Since then, little activity has been undertaken to establish protected areas.

Opportunity: Characteristics of the western Pacific Islands such as high endemism, fragile ecosystems, and dependence on surface water make protection of some forest areas on these islands appropriate. National conservation plans are needed to identify sites that should be protected as permanent preserves and sites to be protected until management's plan can be instituted.

A team effort by appropriate island agencies, U.S. Federal agencies, and local colleges could be used to inventory resources and to design parks and reserves. This would build local managerial capacity and ensure that protected areas fit local needs and conditions.

Current resource inventories conducted cooperatively by local and Federal agencies provide a base of information for protected area establishment. These efforts could be expanded to produce comprehensive natural resource surveys on all the major islands.

Making Undisturbed Forests More Valuable

One method to sustain forest resources is to promote the profitable and sustainable use of animals and plant products other than wood. This could increase the perceived value of the forest without increasing the motivation to overcut its trees. The potential to develop such products is not large in Puerto Rico and the U.S. Virgin Islands, but some opportunities exist, such as small-scale production of honey, bamboo products, eucalyptus leaves and oil, molluscicidal *Phytolacca,* and sphagnum moss for nursery planting (12). The U.S. Forest Service has no permanently assigned economic botanist and local governments have no plans to assess or develop such resources.

The potential for this sort of development seems greater in the western Pacific islands because they have more subsistence-oriented economies. Gathering activities are a normal part of subsistence life on the largely communally owned western Pacific islands. However, this has endangered the Micronesian megapode, a ground-nesting bird whose eggs are considered a delicacy; the dugong, whose vertebrae have been used as wrist and ankle ornaments; and the fruit bat, among others.

Efforts to manage the fruit bat on a sustained basis, including maintenance of its forest habitat, are under way. The Yapese fruit bat is endemic and is Yap's only indigenous mammal. These bats are a traditional food in Yap and are highly sought after by inhabitants of the Marianas as well. The fruit bats also are believed important for fruit tree pollination and seed distribution, especially for mango trees (6). Recently the Government of Yap State banned hunting of the bat. The U.S. Forest Service is

Photo credit: E. Petteys

Efforts to manage the endangered Yapese fruit bat on a sustained basis, including maintenance of its forest habitat, are under way in the U.S. western Pacific

investigating ecology and management of the fruit bats so that hunting can resume without endangering the bat populations or losing the services they provide to the forests.

Opportunity: Assessment of opportunities to develop forest products industries is especially important in the western Pacific. Careful planning is required to avert the threats posed by gathering activities to indigenous animal and plant life. The political activities and biological studies under way to manage fruit bat populations indicate an interest in developing minor forest products. Further opportunities are indicated by experience in other tropical regions. Examples include harvest of nonwood forest products such as essential oils and mangrove aquatic organisms, and innovative forest resource management programs that have the potential to reverse a trend of overharvest.

Technologies to Reduce Overcutting

Methods to reduce the rate of forest degradation from wood harvest and use include: 1) improved harvesting and transport technologies to reduce the extent of forest harvested and to reduce the adverse impacts of harvesting and transport; and 2) reduced demand for wood products through more efficient use of available products (ch. 8).

Industrial Wood

Relatively little potential for full-scale industrial forestry exists in the U.S. territories due to limited forest acreages, topographical factors, competing land uses, small landholdings, high land prices, and uncertain land tenure. However, potential does exist for small-scale industries that can serve domestic markets and contribute to rising living standards (24).

For example, portable sawmills were introduced in Puerto Rico in 1982. Teak, mahogany, and Caribbean pine have been successfully and economically thinned, milled, and marketed by the Puerto Rico Forest Service. There are plans to expand this program. Portable sawmills, combined with regulation of exploitation, are probably the best-suited harvesting systems for the western Pacific as well.

Portable sawmills are especially appropriate for cooperative use because they can be used as needed and temporarily retired without significant economic disadvantages. They require little operator training (24). Because they can be pulled to the harvest site behind small vehicles, they cause less harm to thin soils than larger systems. They do not require an extensive road system and they leave bark and branches on the site, thus reducing nutrient loss.

Small-scale sawmills in rural areas can stimulate development of local workshops with corresponding effects on rural employment. These

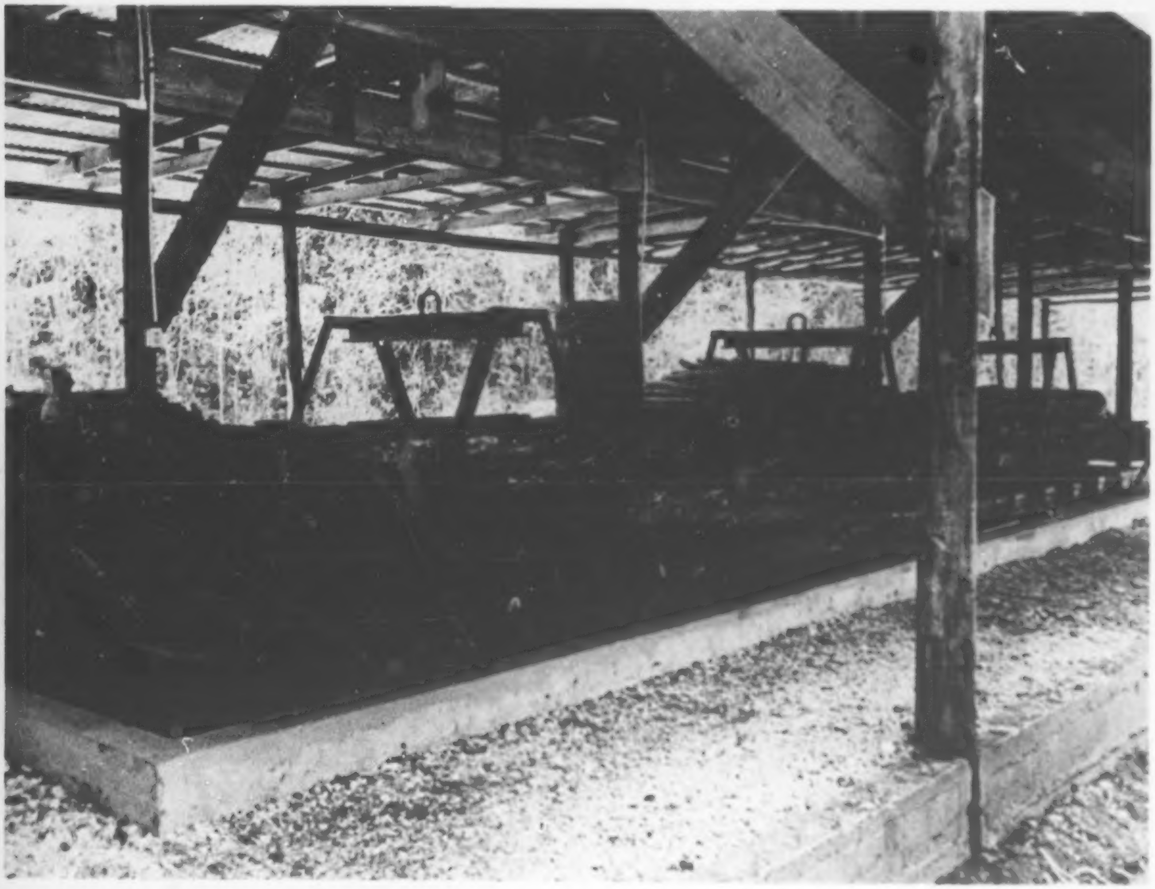


Photo credit: William Balmer

This plant in Cambalache State Forest, Puerto Rico, is treating posts from both private and Commonwealth lands and is helping demonstrate the opportunities for growing and using local wood.

effects could be expanded by introducing facilities such as simple and inexpensive solar kilns or wood preservation equipment. This type of forest industry development can be upgraded as workers improve their skills, local management masters the task, and local markets grow to absorb increased production (24).

Opportunity: Small-scale forest industries that supply local markets could serve as a starting place for a more comprehensive local forestry industry. Rural centers could process wood products from portable mills. This would encourage the creation of a forest constituency to encourage local private organizations and governments to take action to sustain the forest resources. Governments in both the Caribbean and Pacific territories are promoting the creation of private cooperatives in agriculture, although none have yet been organized in forestry.

Wood Fuels

Little need exists to reduce demand for most local wood products in the U.S. territories. Imports have substituted for products previously derived from local forests. However, wood fuels are in short supply in some areas, and wood fuel technologies can be used to increase the efficiency of forest product use.

Firewood is not in high demand in Puerto Rico and the U.S. Virgin Islands, except for some recreational uses. There is significant demand for charcoal for roadside food stands and home uses; charcoal is imported from the United States, Germany, and the Dominican Republic (12). Locally produced charcoal is made by traditional labor-intensive methods using earth kilns. As costs of importing fossil fuels increase, the demand for biomass fuels should increase.

The U.S. Forest Service uses a more efficient, portable kiln on St. Croix, to produce charcoal with wood from thinning and other timber stand improvement work in the Estate Thomas Experimental Forest (23). The Puerto Rico Forest Service operates one demonstration kiln but more activity in this area may be necessary to encourage timber stand improvement (22). In addition, because the demand for fuelwood is relatively low in U.S. tropical forests, they offer an opportunity to study charcoal production and conversion technologies in a stable environment.

The demand for fuelwood in the U.S. western Pacific is rising because of increasing populations and high fossil fuel costs. Perhaps one-third of the Micronesian people have left their rural lands and are concentrated in urban areas (38). They need inexpensive energy for cooking. The availability, transport, and price of fuelwood can vary greatly on an island and from one island to another. Some towns no longer have readily available sources of fuelwood, although accessibility to distant supplies is increasing as roads are improved.

Improved small-scale charcoal production technologies could make wood a more important energy source. Markets for charcoal may exist in Japan and other Asiatic nations. However, this type of commercial involvement should not be promoted until it has been determined that the islands could meet their own needs on a sustained basis. It is likely that man-made plantations and woodlots would be required, although this could also provide a use for scrub and for senescent coconut trees.

Opportunity: Senescent coconut plantations, a major vegetative cover in the U.S. Pacific Islands, could be used to produce charcoal until conventional firewood plantations are established. Old coconut stems cannot be left to rot because of the risk of infestation by the Rhinocerous Beetle, which breeds in the old stems and attacks the newly planted nuts. Unmanaged coconut plantations also provide larval mosquito habitats in water-filled old nuts. The mosquitos have been known to carry elephantiasis, encephalitis, and dengue* (13).

Coconut stems are unsuitable as firewood due to a high moisture content and low density, but they have high thermal efficiency as charcoal. The technologies for producing coconut stem charcoal are simple and well-known. For example, after air-drying, short billets can be burned in simple kilns or 40-gallon drums.

Development of a coconut stem charcoal industry also could provide some spinoff benefits. Coconut shells produce a high grade pharmaceutical charcoal suitable for activation that is used as a filter in many industrial and pharmaceutical uses. High-value, low-volume commodities such as this are potential export products (18).

Technologies for Disturbed Forests

Most of the island territories were cleared in the late 19th and early 20th centuries for export agriculture—primarily sugarcane, tobacco, and coffee. When production declined, rural populations reverted to subsistence and local cash crop production, allowing forests to return on some areas. More recently, as populations migrate to urban areas and as income support programs replace subsistence agriculture, the area of abandoned agricultural lands is again expanding and much of this is reverting to secondary forest.

Data on the extent of secondary forest are not yet available for most of the western Pacific territories, but Guam is estimated to have about

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*OTA is conducting an assessment of biomedical research and related technologies for dealing with tropical diseases.

70,000 unmanaged acres covered with brush or trees and 50,000 acres of open or grass-covered land (38). Secondary forest covers 800,000 acres of Puerto Rico. Forest and brush cover 30,000 acres of the U.S. Virgin Islands.

Much of this land could be used to produce timber and other forest goods, as could some lands that are not naturally regenerating, particularly the savanna lands of the western Pacific. Significant potential for commercial forest plantations exists only for the larger islands of Puerto Rico, American Samoa, Guam, Ponape, and Palau. But small-scale timber stand improvement and village woodlots could supply some needs on smaller islands.

Management of Secondary Forests

Brush and secondary forest in the U.S. Virgin Islands generally is scrubby and of little interest for wood production. A small area on St. Croix might be suitable for this use, but high land prices and land speculation probably prevent secondary forest management from being perceived as a profitable investment.

Puerto Rico has large areas of secondary forest and its management is a primary focus of the U.S. Forest Service Institute of Tropical Forestry (ITF). ITF is conducting an inventory of secondary forest in Puerto Rico. Although most of the trees have little commercial value, the inventory reveals that some valuable timber species are regenerating on abandoned lands. Standard timber stand improvement techniques could result in valuable future timber stands (22).

Some of these techniques such as enrichment line plantings of mahogany are being used in the National and Commonwealth forests. Subsequent harvest provides income for the Puerto Rico Division of Forestry and supports further management of the National Forest. Even though improved timber stands probably will not become a major land use they do have potential to increase the value of private forest landholdings held for other purposes, such as recreation, second homes, or inheritance.

Wood harvest in the western Pacific is limited to fuelwood, some home construction materials, individual tree use by the crafts industry, and some commercial harvest of mangroves (32). Little of the forest has significant potential for commercial timber exploitation because of low volume and poor-quality trees (38). Secondary forest management, however, has considerable potential to provide locally used products—crafts, poles, construction materials, firewood, and charcoal. Cottage-based industries could be developed around local forest products.

Opportunity: Even though managed secondary forest is not likely to become a major land use in the U.S. territories, it merits consideration as an improvement over unmanaged, low-quality brush or forest land unsuitable for agriculture. In Puerto Rico, managed secondary forests can provide a first harvest before conversion to plantation forestry or increase the value of land deliberately held out of intensive production (e.g., recreation sites).

Additionally, secondary forest management will provide a means for the National and Commonwealth forests to gain income for further forestry and preservation efforts. In the western Pacific, managed secondary forests can sustain the supply of raw materials for locally used products. Both efforts require further information on the extent, composition, and quality of secondary forests, and on the current and potential uses of both native and introduced species.

Reforestation

Plantations require more intensive management and a greater initial capital outlay per acre than secondary forests, but usually produce greater wood yields because stocking rates and species composition are controlled. Plantation forestry has greater potential in Puerto Rico than in the other territories because of higher average per capita income and greater land tenure security. An estimated 200,000 acres are suitable for plantation forestry (35,36). No plantation inventory has been conducted in Puerto Rico, but between 35,000 and 95,000 acres of plantations, primarily Caribbean pine, are estimated to exist. Many of these plantings were established in public forests during the 1930's (19).

The yield of a pine plantation in Puerto Rico's moist and wet forests is about 25 cubic meters per hectare per year (2,000 board feet/acre/year) if production is averaged across the rotation (40). Intensive thinning could increase this yield and produce 1,000 or more posts per acre across a 20-year rotation. Thus, establishment of 100,000 acres of softwood plantation could produce 200 million board feet of lumber per year once sustained yields were achieved.

In 1981, 83 million board feet of softwood lumber, 58 million square feet of softwood panels and veneers, and 195,000 poles were imported to Puerto Rico. The land potentially available for plantations could satisfy that level of demand. However, demand is growing at about 5 percent annually. The planting of 5,000 acres per year for the next 20 years would result in 100,000 acres of plantation, but major harvests would not begin until the 21st year.

Photo credit: William Balmer

The pine plantation in the background indicates the wood production potential of these sloped, abandoned agricultural lands in the central highlands of Puerto Rico

Similarly, if 100,000 acres of high-value hardwood plantations were established, the average annual production would be about 70 million board feet. In 1981, 11 million board feet of hardwood lumber and 97 million square feet of hardwood panel and veneer were imported. Here again, the current demand could support a planting program of this scale. Puerto Rico, however, would still import other products such as paper, furniture, veneers, and composites.

Plantation forestry has not attracted much private investment on Puerto Rico for several reasons:

- Private landholdings tend to be small, reducing cost effectiveness of intensive forestry activities and increasing the competition between forestry and other land uses (e.g., agriculture or recreation).
- Shortages of capital and credit for small-plot landholders may not permit investment by rural people in plantation forestry.
- Many private landholders in Puerto Rico hold land for its recreational or future development values and may not be interested in its productive value.
- High land prices and a law limiting private or corporate landholdings to 500 acres may be disincentives to investment in plantation forestry.

Two Federal programs administered by the USDA Agricultural Stabilization and Conservation Service (ASCS) are designed to aid private landowners in forestry activities: the Agricultural Conservation Program (ACP) and the Forestry Incentive Program (FIP). Both provide cost-sharing to small-plot landowners.

FIP and ACP were used only in Puerto Rico. Between 1975 and 1980, there had been only 23 participants in the FIP program in Puerto Rico, reforesting only 213 acres (27). ACP allows greater eligibility and is an older program. From 1936 to 1980, Federal ACP incentives helped to plant over 30,000 acres in Puerto Rico for soil erosion control and commercial purposes. There have been no participants in FIP or ACP in the U.S. Virgin Islands or the U.S. western Pacific territories.

ACP is designed to take land out of annual crop production that would presumably be worth more to society for its environmental services when fallow than for its products when cropped. FIP is oriented toward the greatest return on invested money rather than to widest spread reforestation and, thus, landowners with greater earning capacity have preference over those with greater need for assistance. Neither program assures income during the years before harvest (7).

In recent years, Federal policy has changed emphasis from cost-sharing to income tax incentives to effect forestry practices on private lands. So the budget has been reduced for the ACP and FIP programs. Forestry incentives in Puerto Rico are lost with this change, as citizens there are exempt from paying U.S. Federal income taxes.

Successful programs to stimulate private investment in forestry require the simultaneous development of extension and education programs, nursery production and delivery systems, and trained foresters and forest technicians. Loggers, sawmill operators, and lumber treating and drying experts must be trained, and marketing systems must be developed (19). Since it takes years to develop some of these systems, their simultaneous development must be part of a long-term continuing effort. This requires a stable political commitment.

Until recently, slow progress in forestry has been due to a lack of Federal and local funding and political support. The Commonwealth government for at least 15 years had not put a high priority on forestry. But Puerto Rico now has the legal (Forest Law No. 133 of 1975) and administrative structure (through the Department of Natural Resources) to develop a strong and effective Forest Service.

The Puerto Rico Department of Natural Resources (DNR) has recently embarked on an ambitious program to bring private landowners into commercial forestry. This program relies heavily on U.S. Federal cost-sharing programs for private landholders and on funding from U.S. Forest Service State and Private Forestry grants. Unfortunately, these Federal funds are declining. The program is organized into three phases, as follows: a media program, harvest technology demonstration, and organization of forestry cooperatives.

The U.S. Virgin Islands also has a reforestation program for private landowners, funded by the U.S. Forest Service State and Private Forestry program and by the local government. This program, in operation since 1967, operates a nursery, runs an urban forestry program on public lands, and runs a rural reforestation program. An average of 25 to 30 acres are reforested each year (3).

The goal of the reforestation program is to provide a local supply of high-value hardwoods, especially mahogany. As incentives, the Virgin Islands Forestry Program offers low-cost rental of land-clearing equipment as well as free seedlings and technical advice. In addition, the U.S. Virgin Islands Government offers a 95 percent property tax rebate for lands retained in agriculture or forestry. Most reforested lands are those too steep for cultivation or grazing and, thus, the program indirectly reduces runoff and erosion.

The urban forestry program sponsors planting of mahogany and other species on public lands. Since the potential volume of wood is small in the U.S. Virgin Islands, local production of high-value products seems appropriate. Small and low-value trees removed during thinning could be used for fence posts and charcoal. Even street and yard trees can be valuable: an estimated 500,000 board feet of merchantable mahogany exists in the islands (23).

A small wood crafts and specialty furniture industry exists on St. Croix. Urban and roadside trees that must be removed for other reasons supply much of the raw material. Branches and crotches in the trunk provide figured wood and can be the most valuable part of the tree. This use of available wood could be a model for economic use of wood where large-scale commercial forestry is not feasible.

Transportation costs and insecure land tenure hinder timber production for other than local uses on most western Pacific islands. Some commercial exploitation of lumber for local use could be allowed on larger islands, but in general the forests of the western Pacific islands are too meager to sustain commercial development of forest products such as sawlogs, lumber, wood chips, or paper pulp (15). Local markets for firewood, charcoal, local construction materials, crafts, and fruit crops provide opportunities for investment in tree plantations. Research and demonstration plots of native and introduced species and methods of transferring technologies to villages and private landholders need to be established, especially for intensive firewood plantations.

Opportunity: The U.S. Congress and the U.S. Forest Service could jointly provide political and financial support for DNR and Virgin Islands Department of Agriculture programs to encourage plantation forestry to increase self-sufficiency and build local forest industries. Congress could communicate to the heads of U.S. Caribbean governments the importance Congress places on sustainable development of local forest resources. The Forest Service could provide support for local programs through State and Private Forestry grants. Such actions are needed to ensure continuity of programs despite political changes.

The Forest Service could provide increased technical assistance to U.S. tropical territories in the Pacific to identify areas suitable for investment in plantation forestry and to develop technologies appropriate for forest management under the tropical island conditions. The Forest Service, in cooperation with the Federated States of Micronesia, is using soil and vegetation maps to perform the first forest resource assessment of those islands. Similar assessments could be done to develop plans for other areas.

Forestry Technologies to Support Agriculture

Agroforestry and watershed technologies are designed to use trees to support agricultural and other resources. Coastal resources, in particular, are affected by island forest manage-

Photo credit: William Balmer

Urban forestry in the U.S. Virgin Islands. These trees (hybrid mahogany) will be harvested for lumber

ment. Elevated tropical islands ("high islands") have steep slopes and, where cleared, tend to have high erosion rates. The estimated erosion rates in the U.S. Caribbean compared with the continental U.S. average are 15 times higher for ungrazed forest land, nearly 10 times higher for cleared cropland, and 18 times higher for rangeland.

Agroforestry

Agroforestry is a traditional practice in Puerto Rico (coffee/shade tree, fruit tree/plaintain) and on many Pacific islands (tree/yam, coconut/breadfruit). Teak/forage agroforestry has been practiced in the U.S. Virgin Islands, although this has little potential for expansion (23).

Traditional agroforestry systems are becoming obsolete because of Federal food assistance programs and other alternatives to subsistence food production. The necessary skills and knowledge gradually are being lost on many islands or may reside only in the oldest generation (38). The U.S. Forest Service is beginning a small project to evaluate traditional agroforestry in Micronesia. Through its vegetation mapping project of the Federated States of Mi-

Photo credit: C. Whitesell

Breadfruit—used here to make a canoe—is often used in traditional agroforestry practice in the western Pacific. Although agroforestry has declined in these islands, it retains considerable potential as a productive and sustainable land use

cronesia and Palau, the Forest Service has located considerable acreage that is still used for traditional agroforestry. It can be a sustainable and productive land use, especially on slopes where open-land, bare-soil types of agriculture result in erosion and subsequent siltation.

The U.S. Forest Service Institute of Pacific Islands Forestry is pursuing some research in agroforestry. It includes species trials and nursery development in the Marshall Islands and Yap, studies of the effects of fertilizer on growth and yield of certain agroforestry crops, and growth studies of some tree species. The Institute of Tropical Forestry in Puerto Rico has performed a survey of agroforestry techniques in Latin America (37) but is not conducting further research on this topic.

Opportunity: Improved agroforestry systems alined with traditional techniques should be acceptable to people already using agroforestry and transferable to new practitioners. Agroforestry in place of cleared-land agriculture, especially in mountainous areas, could reduce erosion and siltation and provide a sustainable use for some degraded and marginal lands.

In Puerto Rico, which has better road systems and markets than the other islands, agroforestry producing a cash crop would probably be best accepted. The USDA Mayaguez Institute of Tropical Agriculture in Puerto Rico could perform trials on its experimental lands in cooperation with the U.S. Forest Service.

In the western Pacific, subsistence agroforestry could be appropriate in the short term, combined with research on species suitable for cash-crop agroforestry that could be implemented as markets develop. Western Pacific trials could be performed jointly by the U.S. Forest Service, the University of Guam, the Nekken Forestry Experiment Station on Palau, the Metalinim Forestry Station on Ponape, and with other island organizations and agencies.

Watersheds

The most pronounced impacts of forest loss in the U.S. tropical territories are on island streams and coastal resources. Deforestation has caused permanent streams on some islands to disappear and it contributes to increased runoff, flooding, water shortages, and erosion. Siltation has harmful effects on lagoons and reefs, affecting fish and other marine resources important to island people.

Most upper watersheds in Puerto Rico have steep slopes and many should remain forest-covered. In general, these lands are also too steep for significant wood harvest. With appropriate regulation, however, some gathering, recreation activities, and residential development might be allowed.

The U.S. Virgin Islands have major water problems. There are no permanent streams on the islands. Island aquifer water levels are declining as growing populations pump out more water than is recharged. Water supplies are derived primarily from costly desalinization of sea water and water barged in from Puerto Rico. Watersheds in the U.S. Virgin Islands are privately owned and mostly brush covered. Some livestock is run on these lands, but there is little agriculture, except on St. Croix. Nothing is done collectively to manage these lands for water retention and erosion prevention.

Natural siltation in the western Pacific region is greatest around high islands. Elevated watersheds collect and accelerate runoff. Around these islands, however, mangrove forests and stands of seagrass act as filters to remove sediments before the runoff water reaches lagoons or reefs. In many areas, erosion and marine siltation have been accelerated by deforestation, so that plumes of eroded soils often are seen near the mouths of streams in Micronesia. The silt represents a lost resource and pollutes the marine environment. Activities that aggravate soil erosion include cultivation practices, construction, roadbuilding, and burning, which removes vegetative cover from hills. Due to repeated burnings on Northern Babeldaob (Palau), formerly permanent streams now run only when rain falls, and then they are often fast and muddy (5).

Photo credit: William Balmer

This plantation of blue mahoe *(Hibiscus elatus)*, a valuable hardwood that gorws well on many moist sites in Puerto Rico like others planted on private lands, was established for watershed protection

Opportunity: Resource managers disagree on the relative advantages of reforesting watersheds or leaving them in grass and brush cover. Reforestation reduces runoff and erosion rates and so increases catchment lifetimes and protects coastal resources. Some experts believe it might increase aquifer recharge. On the other hand, trees use more water than grass and brush, so tree planting reduces the amount of water immediately available to catchments. Degraded pasture and brush are more susceptible to frequent burning and conversion to unsustainable land uses than are managed forests (22). A careful assessment is required to determine the optimal vegetation cover for each watershed area. There seems little doubt that steep coastal slopes should be forested to reduce erosion and, thus, reduce siltation of lagoons, reefs, and mangroves.

Resource Development Planning

Most conversion of tropical forest land to other uses is done without adequate consideration of whether the natural and human resources available at the site can sustain the new land uses. Resource development planning is a systematic attempt to match land development activities to the capabilities of the specific sites (ch. 11).

Puerto Rico and the U.S. Virgin Islands have been extensively studied and are classified under the Beard system, based on floristics and species composition (1,2); the Holdridge Land Classification System, based on precipitation, biotemperature, and potential evapotranspiration (8,9); and the USDA Soil Conservation Land Capability System (28). Because land uses and vegetation are continuously changing, detailed land classification data require continued updating and revision.

In the U.S. tropical territories, little use has been made of economic and social assessments for forestry development. The Puerto Rico Department of Natural Resources has conducted a benefit-cost analysis of an expanded forest tree planting and wood-use program based on small-scale harvesting (19). DNR has also prepared a financial analysis of small-scale private forestry (20).

Knowledge of the remaining tropical forests in the western Pacific, the local uses of tropical forest products (e.g., medicines), and local customs involving forests is insufficient for planning. Information on the nature and magnitude of the forest resources, including vegetation, land use, watershed, wildlife, commercial timber, and ecosystems is either lacking or too scattered to assist forest management planning and protection programs.

The U.S. Trust Territory of the Pacific Islands (TTPI) Government contracted with the U.S. Soil Conservation Service and the U.S. Forest Service to map the soils and vegetation cover types of the Republic of Palau and the four states of the Federated States of Micronesia. These soil and vegetation maps are used in land-use planning and are being used to conduct the first forest resource assessment of the Federated States of Micronesia. Preparation of State/Territorial Forest Resource Program Plans is expected to be completed in 1983.

Similar assessments could be conducted elsewhere in the western Pacific (38). Current guidelines and funding permit the U.S. Forest Service to conduct resource inventories and forest management research **only when** cooperating island governments provide funding and field assistance (4). The U.S. Forest Service has memoranda of understanding with each of the island governments regarding resource assessments, but inadequate funding has hindered completion of these efforts.

A complementary series of assessments by the U.S. Fish and Wildlife Service could determine damage by and control measures needed for introduced animal species, effects of land uses on coastal organisms, conservation measures for endemic species, and other topics. The U.S. Fish and Wildlife Service has recently completed an ornithological and botanical survey on Guam. Additional "terrestrial surveys" in the northern Mariana Islands are under way. Similar surveys are expected to be undertaken on Ponape, Truk, Yap, and Kosrae (17), but budget reductions have postponed these efforts (39).

Opportunity: Resource development planning could help identify where agricultural activities should be limited and where they might require special designs. Similarly, such planning could help determine optimal sites for roads from both ecological and social points of view. To supplement this, island government agencies could prepare environmental impact statements, hold public hearings, and seek approval from the appropriate local resource agency to control and monitor logging, land clearing, road construction, coral mining, etc. (38). The U.S. Forest Service and Army Corps of Engineers could provide assistance when road-building activities are being planned.

Education, Research, and Technology Transfer

Lack of awareness of forest resource values, shortages of forest resource professionals, and insufficient technology transfer are institutional constraints that inhibit development of sustainable forest systems in the U.S. Caribbean and western Pacific territories (ch. 12).

Environmental Education

Government decisionmakers in the U.S. territories have expressed growing interest in sustaining and developing their forest resources. However, this interest may be temporary unless people at all levels of society seek alternatives to resource-degrading activities and invest in resource-sustaining technologies. Motivating such action is the goal of environmental education.

Like other New World colonies, many Caribbean islands were almost completely cut over to produce agricultural export crops between 1800 and 1898, producing a "burn the forests" attitude toward development (14). As yet, rising incomes and education have not brought about a widespread environmental awareness movement such as that in the continental United States. The result has been a continuing view that the forest is useful for recreation and tourism but must be removed to make way for more productive investments (7). This has begun to change only recently.

A primary forestry objective of the Puerto Rico DNR is to change public attitudes through education and incentives to involve people in forestry policy and activities. DNR has one or two field agents in each of the five regions of Puerto Rico who receive 2 weeks of forestry training. This training is to be updated regularly. In addition, pamphlets on forest planting may now be found in all Agricultural Extension Offices and a new pamphlet on the financial opportunities of timber production on private lands will soon be disseminated (21).

Education also has been a major focus of U.S. assistance to the western Pacific territories. Primary and secondary education are compulsory in Micronesia, and the Federal Government has helped create several community colleges and the University of Guam. Each of these has been designated a land-grant college, giving them access to Federal support for agriculture and forestry.

Many of the inhabitants of the island territories can be reached through education because of the young age structure. For example, 44 percent of Micronesia's population in 1980 was under the age of 15. Under the Compact of Free Association agreement, the U.S. Government will continue to fund public education, including a $3 million grant for a higher education scholarship fund. But many of these scholarships are based on financial need and not on the field of study needed for economic growth (33). Increased exposure to environmental education in primary and secondary schools, together with awarding scholarships to students interested in resource development, may be the first steps toward creating environmental awareness.

Opportunity: The Puerto Rican Government could begin to encourage resource-conserving attitudes by increasing environmental education at all levels. Three interacting activities that could have significant effects are:

1. Create training courses for primary and secondary level teachers using protected forests as demonstration areas.

Photo credit: USFS-ITF

Youth conservation worker programs can introduce local people to basic principles of ecology and forest management. Here, Young American Conservation Corps enrollees plant mahogany in a Puerto Rican public forest

2. Increase use of local youth conservation workers in National and Commonwealth forests and other natural resource areas.*
3. Make forest resource management an area of study at the University of Puerto Rico either by developing a resource management curriculum or by creating a "center of excellence" to provide a focus of interest and efforts on tropical forest resources (ch. 12).

Environmental education in the U.S. western Pacific seems to have had little effect (15). The U.S. Forest Service, U.S. Fish and Wildlife Service, National Park Service, National Marine Fisheries Service, Peace Corps, and local colleges could collaborate to produce course materials that stress resource awareness and encourage the territorial governments to include resource and conservation programs in school curricula. They could also translate technical environmental information for general public use (29).

Professional Education and Technical Training

The U.S. tropical territories do not have a strong constituency concerned with forest conservation. Developing such a constituency and integrating natural resource considerations into economic development both will require personnel with substantial knowledge and expertise in natural resource management in general and tropical forestry in particular. In the short term, a limited number of resource professionals with expertise in tropical forestry can be attracted to the islands from the mainland. But the Forest Service reward structure inhibits this, and lack of scientific facilities and funding hinder university personnel. In the long run, an effective method to educate and train local people is needed.

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*Currently, Young American Conservation Corps (YACC) workers in Puerto Rico are trained by ITF personnel and assigned to Commonwealth and National Forests (30).

The University of Puerto Rico lacks a forestry curriculum. Puerto Rico and the U.S. Virgin Islands support only two students per year in forestry and forest ecology training. A similar dearth of forestry specialists exists in the U.S. western Pacific. No forestry curriculum exists at the University of Guam, although officials have expressed a strong interest in developing one (4). The closest forestry school is at the forest ranger school at the University of Bulolo in Papua New Guinea. The need for trained foresters and forest technicians is particularly acute as the island governments expand their government forestry agencies and forestry plans.

Opportunity: Fostering natural resource management training and education in the U.S. territories could be achieved in four ways:

1. Students interested in natural resource management could be encouraged to apply for scholarships at U.S. schools and internships with private organizations. The best sponsors for such scholarships might be private firms with production facilities or markets in the territories.
2. Scholarships also could be provided for forest technician students to attend natural resource management programs in tropical country schools (e.g., Costa Rica, Venezuela, Papua New Guinea), where technical training may be more relevant.
3. Forestry/forest ecology/conservation curricula could be developed at the University of Puerto Rico and the University of Guam, possibly using McIntyre-Stennis funds.*
4. Forestry institutions in each region could be designated "centers of excellence" in education and research related to tropical forestry resources and as such could provide graduate study and research facilities for students from U.S. and tropical universities (ch. 12).

Research

The U.S. Forest Service Institute of Tropical Forestry (ITF) was established in 1939 as a result of congressional recognition that lack of technical knowledge hindered successful reforestation and forestry efforts in Puerto Rico. ITF uses the National Forest, some Commonwealth forests, and the 124-acre Estate Thomas Experimental Forest in the U.S. Virgin Islands for research. ITF conducts cooperative research with agencies such as AID, the Peace Corps, U.S. Fish and Wildlife Service, and several universities and Caribbean nation governments. Recent ITF research is intended to:

- develop guidelines to establish and manage timber plantations (primarily pines and exotic hardwoods) without adversely affecting site productivity;
- develop knowledge about biological potential of timber production from secondary forests, with due regard for other environmental concerns; and
- develop knowledge about forest wildlife habitat requirements and techniques to manage these habitats (focusing on the endangered Puerto Rican parrot and associated species).

ITF research activities have traditionally focused on basic ecology and industrial forestry. The latter is not widely applicable to the U.S. Caribbean. Only about 6 percent of landholdings are 100 acres or greater, but these cover 65 percent of farmland. Most of these larger holdings are commercial farms on the coastal plains or coffee plantations on hilly regions. Many of the large-plot landowners in forested regions may be real estate investors waiting for land prices in the U.S. Caribbean to increase, and as such may be uninterested in productive uses of their land. Environmental education and extension efforts could be made to change this attitude and some commercial forestry research should be conducted for these landowners.

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*The McIntyre-Stennis Act of 1962 authorizes cooperative forestry research between the U.S. Department of Agriculture and state and land-grant universities.

However, research directions have begun to change in recent years. Since the Forest and Rangeland Renewable Resources Research Act of 1978 (Public Law 95-307) and the concurrent growth in interest in international forestry, ITF has conducted a survey of agroforestry in Latin America (37) and studies of fuelwood production (30). Yet, ITF budgets have been cut back continuously for the past few years and the primary focus is still on industrial production.

Industrial forestry research at the ITF could be complemented by research aimed at the needs of Caribbean society in general (e.g., environmental services, esthetics) and of the small-plot landholder. Nearly 90 percent of the farmland ownerships (covering 270,000 acres), are less than 48 acres (26). Most of these landowners have low incomes. Rural unemployment is high, implying a need for labor-intensive technologies. Profitable agroforestry systems to produce both subsistence and commercial products need to be developed and disseminated. Industrial forestry research could be appropriate for this group if forestry cooperatives were organized. Research areas such as watershed and wildlife management, which provide benefits to society in general, deserve more attention, particularly given the water problems in the U.S. Virgin Islands.

Although the U.S. Virgin Islands have little agriculture and little potential for commercial forestry, protective forestry activities are necessary to preserve resources for the inhabitants and for tourism. ITF research in the Estate Thomas Experimental Forest could be expanded to include experimental urban forestry, watershed analyses, and other appropriate topics. More research personnel and funding and selection of research topics more relevant to local research needs are necessary.

The American Pacific Islands Forestry Research Work Unit, at the Institute of Pacific Islands Forestry, is part of the U.S. Forest Service Pacific Southwest Forest and Range Experiment Station. The Research Work Unit has only three professional staff comprising 2 scientist-years. It is involved in:

- conducting resource inventories in cooperation with Island governments;
- testing native and introduced tree species, especially nitrogen-fixing trees;
- developing silvicultural methods for reforesting understocked savanna uplands and deforested coastal areas, thereby increasing protection and use of critical watersheds, and/or for timber production;
- publishing a nontechnical handbook on forest reestablishment;
- selecting, establishing, protecting, and using natural areas;
- analyzing performance of selected coconut varieties on tropical islands and atolls;
- studying potential for sustained-yield management of the indigenous fruit bat; and
- developing cultural practices to maximize yields of selected agroforestry crops (31,39).

As the U.S. Trust Territory of the Pacific Islands government infrastructure is dismantled, the Research Work Unit is developing close working relations with the extant and emerging governments in American Samoa and Micronesia. More personnel and funding will be required to make the best use of this institution.

Technology Transfer

Forestry extension agents and activities in Puerto Rico and the U.S. Virgin Islands are few. Although there are a number of field agents who advise landowners on land-use alternatives in the U.S. Caribbean (Department of Natural Resources, U.S. Soil Conservation Service, and U.S. Agricultural Extension Service agents), few have been trained in forestry. Field agents have little incentive to seek this training because they typically are responsible for many areas of extension and little of their time is devoted to forestry. Rural landowners must rely on the extension and media activities of the Puerto Rico DNR and the ITF to become informed of techniques and available incentives.

One U.S. Forest Service person is responsible for State and Private Forestry in Puerto Rico and the U.S. Virgin Islands. He helps the Puerto Rico DNR apply for U.S. Forest Service grants and coordinates U.S. participation in the Cooperative Forest Management Act. This act allows the U.S. Forest Service to cooperate with the DNR to promote reforestation and protection of public and private lands (14). There also is only one person assigned to State and private forestry activities for Hawaii and the western Pacific.

The forestry agencies in the western Pacific do not have organized extension services. Distances between islands compound the problems of devising technologies appropriate to the area and people. Scientists and technology developers usually can visit only a few islands.

Opportunity: The U.S. Forest Service could support Puerto Rican forestry programs through increased State forestry grants. These grants seem an effective means of stimulating the Commonwealth Forest Service to support, coordinate, and demonstrate desirable forestry practices. The flexibility and individuality of the State grant program allow specific application of funding to U.S. Caribbean problems. This would require increased personnel for the U.S. Forest Service State and Private Forestry in Puerto Rico. Foresters from the United States who are experienced in aiding State forestry organizations can be effective in advising on nursery operations, logging techniques, use strategies, genetic improvement programs, research needs, extension practices, and other elements of program development.

Congress has made special allowance for the Peace Corps to operate in the U.S. Trust Territory, at least until the Compact of Free Association is signed. These volunteers could provide a means for technology transfer and for feedback to researchers regarding needed adaptations of technologies. The Peace Corps could ensure that all its rural volunteers have at least some forestry training and are in contact with the appropriate agencies for technical aid.

A cadre of local, "grass-roots" naturalists could be created in the U.S. western Pacific with help from the U.S. Forest Service, Department of the Interior, Peace Corps, and island governments and universities. Such a program could provide general training that would qualify participants to assist both permanent and visiting research scientists. They could help spread information on appropriate land uses and help integrate new technologies with local customs (38).

CONCLUSION

If tropical forest resources are to be sustained in the U.S. territories, indigenous resource management organizations must be strengthened. Because these governments are still heavily reliant on U.S. assistance and their resource agencies are in their infancy, the United States retains a substantial role in developing both the agencies and resource-sustaining technologies.

In the short run, U.S. technical assistance is needed to design forest management plans. In the long run, this assistance could be replaced by a skilled cadre of people trained in natural resource management at local institutions. Programs to encourage private forestry for each island probably will also require U.S. Federal assistance. The Federal institutions responsible for assisting forestry in the U.S. tropical territories are too small and their focus is too limited to give adequate impetus to local investment. More research and more forestry technology transfer are required, as is greater response to the changing needs of the territories.

Application of U.S. Expertise: U.S. expertise relevant to tropical forest resources is not used effectively in the U.S. tropical territories. This is partly because many experts consider the U.S. tropical territories a relatively insignificant part of the overall tropical forest resource conservation problem and partly because organizations that might be used to focus professional expertise on the U.S. tropics do not have the necessary support to do so.

Definition of Roles in U.S. Western Pacific: Resource development planning in the western Pacific territories is constrained by a lack of definition of the respective roles of local, U.S. Federal, and international organizations. Little analysis and no decisions have been made on the question of whether the authority of the U.S. Federal agencies is adequate or appropriate to serve the resource needs of Micronesia and American Samoa (29). In particular, with the political changes in the region, applicable Federal programs must be identified and directed toward island needs. Under new agreements with territory governments, U.S. support is planned to be offered primarily in cash rather than through Federal categorical programs, although room is left for extension of agreed-upon programs (34).

The Interagency Task Force on U.S. Territories* could conduct a comprehensive review of Federal legislation applicable to natural resource use in the western Pacific area. This effort could identify legislation needed to support sustainable natural resource development. It also could identify alternative ways to implement legislation that would both sustain the resources and achieve the goals of the agencies (29).

Local Resource Agencies: Opportunities exist to use forest-resource sustaining technologies in western Pacific territories. The territorial governments all have designated natural resource agencies with a forestry component. But these agencies are relatively new and do not yet have adequate funding, professional personnel or policies to take full advantage of the opportunities.

Political support for the natural resource agencies seems to exist. However, there has been very limited planning for the forested areas. In practice, some forestry has concentrated on nursery planting and extension without operational plans or assignment of responsibility (4). Without more outside assistance, development is likely to proceed so slowly that needed resource productivity and economic opportunities will be lost.

The Federal Resources Planning Act of 1974 (RPA) as amended, the Cooperative Forestry Assistance Act of 1978, and other recent legislation have extended the prospects of Federal forestry assistance to Pacific islands. The U.S. Forest Service could increase aid to territorial governments in developing natural resource agencies, provide technical assistance for resource assessments, help develop policies, management, and enforcement plans, and provide technical assistance for implementation.

Private Forest Investment Programs: Programs designed for the U.S. continental States to promote soil and water conservation and private reforestation usually do not apply well to tropical island characteristics. For example, small landholding size, low income, and lack of technical knowledge prohibit many rural landholders in Puerto Rico from participating in reforestation.

Because the U.S. tropical territories are so different from the 50 States—politically, economically, culturally, and ecologically—investment incentive programs designed for the States are unlikely to be effective in the islands. And because the territories are themselves heterogeneous, a single program probably cannot be designed to be effective on all islands. An alternative is to make funds and technical assistance available to private investors through individual territorial governments.

Congress could create a reforestation incentives program that could: 1) be operated jointly by the U.S. Forest Service and the territorial governments, 2) be designed specifically for local characteristics, 3) be integrated with other natural resource development objectives, 4) include agroforestry and/or an annual loan to provide early income before harvest, and 5) encourage organization of forestry cooperatives. More generally, Congress could analyze all legislation involving proposed or actual natural resource programs that might be applicable to the U.S. territories and write in language ensuring applicability to the needs of the territories (20,25). Alternatively, it could create complementary but different natural resource conservation and use programs designed specifically for the characteristics and needs of the territories.

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*The Interagency Task Force on U.S. Territories includes representatives from most Federal agencies, including Housing and Urban Development, Health and Human Services, Education, Defense, Commerce, Interior, Agriculture, and the Environmental Protection Agency. It is housed under the Department of the Interior's Office of Territorial and International Affairs.

U.S. Forest Service Institutes located in Puerto Rico and Hawaii are assisting the territories in developing technologies and institutions to sustain tropical forest resources. However, both institutes have too few staff and budgets that are small and declining. They cannot support the scale of development activity necessary to sustain the U.S. tropical forest resources. If the institutions are given further responsibilities in international forestry without new funding and personnel, their effectiveness will be diminished.

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PART III

Options for Congress

Chapter 14

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Chapter 14

Options for Congress

HIGHLIGHTS

- Forestry projects sponsored by the U.S. Agency for International Development (AID), the United Nations, the World Bank, and other agencies are poorly coordinated.
- Many opportunities exist to modify development assistance practices so they produce economic benefits while sustaining renewable resources.
- Resource development planning can help maintain tropical forest resources and simultaneously make economic development more profitable, but the techniques to do so are underused.
- Research on tropical forest resources needs to be more interdisciplinary and linked more closely to the needs of technology users.
- Developed nations benefit from the tropical forests' biological diversity, so they could pay a share of the costs of preserving natural forests.
- Demand for U.S. expertise in tropical forest resources is increasing, but U.S. organizations are not well organized or supported to use the limited existing expertise efficiently or to build more expertise.
- Forest resources in the U.S. tropical territories generally are degraded, underdeveloped, and inadequately managed.

INTRODUCTION

Tropical forests in U.S. territories and in other nations are important to the United States. Forests support economic progress in tropical countries, progress which is important for humanitarian reasons and for political stability. They supply fuel, food, fodder, and materials and will be increasingly important as population doubles over the next 30 years. Tropical forests also provide many materials used by U.S. industry and consumers. Moreover, they contain a great diversity of biological resources. This is important to U.S. agriculture and medicine and will become more important as nonrenewable resources are depleted. In addition, forests have significant beneficial effects on the conservation of soil and water resources and maintenance of environmental quality.

Although data on the condition of tropical forest resources are poor, information on their extent and location is improving. Recent studies indicate that tropical forests are being degraded rapidly by unmanaged exploitation and that substantial areas are being deforested for unsustainable land uses.

Rates of deforestation and forest degradation, and the severity of the consequences, vary greatly from region to region. From a near-term economic and social perspective, the loss of trees is most damaging in dry areas, where deforestation is both a cause and an effect of desertification, and in mountainous watersheds, where deforestation upsets the hydrologic cycle and accelerates soil erosion. Resource degradation and deforestation in the humid tropics are resulting in permanent loss of biological resources.

Many organizations, some funded entirely or partly by the U.S. Government, are grappling with tropical forest resource problems. Funding and levels of effort have risen substantially during the past 5 years, and progress has been made in developing and transferring technologies that can help sustain tropical forests, both in natural and modified condition. Yet, the rate of technology improvement does not seem sufficient to overcome the processes of forest resource degradation.

Further increases in U.S. and international funding to develop and disseminate technologies will be necessary. But incremental changes in current techniques alone will not suffice to sustain tropical forests. The underlying causes of deforestation and resource degradation are institutional, social, and economic. Consequently, many needed reforms can only come from the governments and people of the tropical nations. Here, too, the United States can be effective by helping tropical country governments focus on root problems.

The ultimate objective of forest resource development is to support people. Future generations are expected to need forest products and services as much as those of the past, so production of forest goods and services must increase as fast as population growth. Today, increasing yields of forest products are accomplished in most tropical regions by sacrificing the renewability of resources.

Investment in technologies discussed in previous chapters of this report might make it possible to achieve the necessary production while sustaining the inherent renewability, at least for a time. However, if population growth is not controlled, development and conservation objectives eventually will not be attainable. Technologies directly related to population growth are outside the scope of this assessment but have been addressed in another OTA assessment, *World Population and Fertility Planning Technologies.*[1]

U.S. technology has helped stimulate institutional reforms. For example, U.S.-trained analysts in tropical countries working with U.S.-provided Landsat imagery have documented deforestation rates (e.g., 2.7 percent per year in Thailand) that have motivated national governments to institute new laws giving forest conservation a higher priority. U.S. diplomacy—e.g., supporting and influencing the United Nations' Environment Program and UNESCO's Man and the Biosphere program—has been effective in raising international awareness of tropical forest problems.

Forests in U.S. Caribbean and western Pacific island territories have hardly benefited from the increased international awareness of the importance of sustainable forest resource development. Those forests continue to receive little, if any, management, and data on erosion indicate that their potential productivity is being reduced.

Tropical forest resources represent a great opportunity for sustained development. However, because of complex institutional and technical constraints, too little such development is occurring. Congress can encourage sustainable development of forest resources in the U.S. territories by giving these areas higher priority in domestic natural resource programs. It also could direct domestic agencies to adapt programs to the special situations that prevail on tropical islands. For other nations congressional action can help resolve some institutional constraints by enhancing tropical governments' abilities to plan and coordinate resource development projects.

Some technical constraints can be addressed directly through congressional actions. U.S. organizations and individuals have the capability to assist in developing forest use systems that provide goods and services for the basic needs of tropical people while conserving forest productivity. U.S. agencies already applying some of this expertise include the Agency for International Development, Forest Service, National Academy of Sciences, National Park Service, Fish and Wildlife Service, and Soil Conservation Service.

Congress also could act to improve U.S. efforts in technology development. Some actions, such as the establishment of U.S. centers of excellence in tropical forestry or increased U.S. participation in multilateral agencies, would require increased funding in the near term. In the long term, however, these actions should improve the tropical nations' own abilities to use and sustain forest resources and, thus, should reduce the need for U.S. Government involvement. Other opportunities such as improved coordination of fundamental research, applied research, and technology implementation do not necessarily require additional funding but could require redefinition of priorities.

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[1] *World Population and Fertility Planning Technologies: The Next 20 Years* (Washington, D.C.: U.S. Congress, Office of Technology Assessment, OTA-HR-157, February 1982).

This chapter identifies several major issues where Congress could take significant action to improve conservation and sustainable development of tropical forest resources. For each issue, options for specific actions and their advantages and disadvantages are discussed.

U.S. TROPICAL FORESTS

Issue

Most forest resources in U.S. tropical territories are not now being overexploited, but neither are they being managed or developed. The territories lack strong institutions concerned about the productivity and sustainability of forest resources. Thus, when the demand for land or jobs increases, the productive potential of the forests is likely to be sacrificed.

Most forests in the U.S. tropical territories are substantially degraded from their original condition. However, because of U.S. Federal income supports and the relatively low population pressure on some islands, little incentive exists to exploit them further. There is also little incentive to develop and conserve the forest.

Whether the forests are stable in their degraded condition, improving, or continuing to degrade is unclear. Probably all these processes are occurring in different places. Available data on soil erosion rates and anecdotal evidence suggest that the potential productivity of the islands forests is being lost gradually.

Continued existence of large acreages of relatively unproductive forest land may promote the idea that forests should be removed to make way for development. Forests need to be managed as an integral part of overall island resource development, especially to protect watersheds and coastal marine environments.

Over the long term, as populations grow and Federal supports decline, the productivity of the forests will become more important and yet more difficult to sustain. Whether that productivity will be realized depends on how soon forestry becomes integrated into the economic development of rural areas. Getting the necessary support for forestry depends on building an informed group of people who perceive that they will gain from forest conservation.

The U.S. Forest Service's Institute of Tropical Forestry (Puerto Rico) and Institute of Pacific Islands Forestry (Hawaii) will continue to have the major roles in researching and demonstrating forestry technologies until territorial natural resource agencies become sufficient. Low levels of onsite research and demonstration will inhibit growth of a constituency that wants and uses appropriate forest management technologies. Meanwhile, without such technologies, rising populations and expectations are likely to result in eventual degradation of the forest resources.

Unfortunately, many experts consider the U.S. tropical forests to be a relatively insignificant part of the overall tropical forest conservation problem. Further, the institutions that might be expected to provide professional resource development expertise in the U.S. tropical territories lack the necessary support to do so.

Natural resource agencies in U.S. tropical territories are small or exist in name only. They require increased funding, professional personnel, and technical assistance to be effective. In addition, Federal resource conservation and production programs for privately owned forests are, in general, not compatible with the characteristics of the U.S. tropical territories. These program funds might be more effective if they supported private forestry programs designed and administered by territorial forest agencies.

Option 1:

Congress could increase funding for U.S. Forest Service research and technology development and could direct the Forest Service to increase coordination of its activities with other resource agencies in the U.S. tropical territories.

The Forest Service institutes in Puerto Rico and Hawaii have small budgets and have been cut back recently. These organizations have too few staff to support the scale of activity necessary to sustain U.S. tropical forest resources. Increased budgets and greater participation by U.S. tropical forest experts are needed.

This option might be coupled with option 22, which is to establish U.S. centers of excellence to focus U.S. research, teaching, and resource development expertise related to forest resources. Such centers could demonstrate a variety of sustainable management technologies at sites in the U.S. tropical territories. They also would help develop the territories' human resources by supporting education and training activities.

More integration of U.S. Forest Service activities with the objectives and programs of territorial agencies responsible for resources other than forests (e.g., water and coastal marine resources) could help ensure that technologies are appropriate to the social and ecological needs of individual islands. Also, cooperative activities could provide a way to help the local agencies prepare to eventually assume total responsibility.

This option would require increased funding for the U.S. Forest Service institutes and could require some reordering of research priorities to increase emphasis on such topics as watershed management and agroforestry. Unless new moneys were appropriated, the funds might have to be transferred from other U.S. Forest Service programs. Competition for such funds probably would be great.

Option 2:

Congress could support natural resource agencies in U.S. territories by increasing funding for the cooperative State and private forestry programs of the U.S. Forest Service institutes in Puerto Rico and Hawaii. Congress could also create a program of grants to territorial governments to encourage investment in privately owned forests.

Stronger local capacity to manage forest resources would contribute to the territories' self-sufficiency. In the long run, it might reduce the need for development assistance from the United States. Forestry could provide rural employment and increase sustainable production of food, wood, and other products that could be used instead of subsidized imports. A stronger local research capability could help ensure applicability of technologies to local conditions and could reduce dependence on research performed by the U.S. Forest Service.

The Federal Government subsidizes private forestry with cost sharing and direct payments to forest owners. Replacing these subsidies with a program of grants administered by the territorial governments would provide the flexibility needed to respond to each island territory's unique cultural, economic, and ecological characteristics. Furthermore, it would encourage the development of a constituency concerned with sustaining the forest resources. Such a program could be used to keep the benefits available if the Federal forestry cost-sharing programs in other areas were replaced with income tax incentives as has been proposed.

This option would require increased funds for the Forest Service institutes both for dispersal to local natural resource agencies and for increased administrative and professional personnel. State and private forestry funds (for grants, loans, subsidized inputs, and extension services) have been declining and would need to be increased. This could either be new money or money reallocated from other U.S. Forest

Service programs, but these programs have been cut substantially in recent years. In the short term, the local natural resource agencies might not have the human and logistical resources necessary to implement a greatly expanded program.

This option also would require new negotiations with the emerging Pacific territory governments to determine the guidelines for forestry program assistance. No resource programs are included under the Compact of Free Association. The roles of local, U.S., and international resource agencies in the U.S. Pacific territories need to be defined to coordinate actions.

DEVELOPMENT ASSISTANCE

Issue (Projects)

Development assistance is making progress to sustain tropical forests, but the gains are insufficient to offset resource degradation. Many opportunities exist to continue and accelerate the progress. But congressional vigilance is necessary to ensure that forestry projects receive an appropriate share of U.S. development assistance funds and that other types of projects complement the forestry efforts.

The Foreign Assistance Act directs development assistance organizations in which the United States participates to give higher priority to the problems of loss and degradation of tropical forests. AID, the World Bank, the U.N. Food and Agriculture Organization (FAO), and some other multilateral organizations have increased funding for forest-related projects. Furthermore, AID has developed new forestry and environmental strategies and policies. Additional opportunities for development assistance projects to sustain tropical forest resources include greater support for:

- Participation by local people in identifying resource development problems and opportunities.
- Agriculture and rural development programs that increase productivity for people who live near forests. This would entail allocating a larger share of agricultural development assistance to relatively remote areas.
- Agroforestry and innovative crops and techniques that can sustain permanent agriculture on relatively poor soils.
- Locating new agricultural settlements where the natural and human resources are capable of sustaining farming practices used. In some cases, this would mean refusing support for settlement projects planned for closed forest areas and redirecting settlements to sparsely populated areas that are not forested.
- Reforestation and management of natural forests to sustain environmental services and produce fuelwood, construction wood, polewood, and nonwood products.
- Development and dissemination of locally acceptable technologies to make woodfuel use more efficient.
- Long-range planning for infrastructure development projects (e.g., hydroelectric dams), so that wood from clearing operations is used effectively, displaced farmers are resettled permanently, and watersheds are protected by forest cover.
- Institution-building to enable tropical governments to exercise improved control over timber concession operators.
- Technical improvement and increased application of technologies for sustainable regeneration in logged forests, including mangrove forests.
- Plantations of fast-growing industrial tree species to help take pressure off the remaining natural forests.
- Financing wood product development projects that encourage domestic processing as opposed to log exports.
- Innovative institutional approaches to forestry and agroforestry designed to ensure participation of local communities and to

increase diffusion of appropriate technologies beyond the boundaries of subsidized demonstration projects.
- Livestock raising projects that do not result in deforestation or forest degradation.

Option 3:

Committees of Congress could continue periodic oversight hearings requiring testimony from AID and U.S. representatives to multilateral development assistance organizations on the extent to which development assistance practices are being modified to accomplish the objectives set forth in section 118 of the Foreign Assistance Act.

Development assistance projects can be planned to produce improvements in income and income distribution and to simultaneously provide long-term conservation benefits. Such projects are being pursued to some extent by the various agencies. AID has one of the best records in this regard. However, the total effort is still small compared with other, more conventional approaches to agricultural and industrial development. Continued pressure from Congress, especially on the multilateral organizations, might lead to greater investments in resource-conserving projects. This in turn could result in more cost-effective and sustainable economic development and, eventually, in a reduced need for U.S. Government involvement.

Placing a higher priority on resource-conserving forest development might have some disadvantages. First, higher priority for these approaches means lower priority for some others. For example, investment in agricultural development in remote areas at the forest fringe may not produce short-term yield increases as great as the same amount of investment in already-developed farms on more fertile lands.

Projects designed to increase revenues available for forest management by making forestry more profitable or more sustainable have some other drawbacks. For example, promoting manufacture of wood products within tropical countries might reduce opportunities for employment and profits in industrial countries that now import logs and do the manufacturing.

Issue (Coordination)

Development assistance organizations generally do not coordinate their projects effectively at the country or regional level. To improve effectiveness, projects could be organized as steps in a comprehensive strategy designed to develop sustainable forest management systems. Individual development assistance organizations have neither developed nor coordinated such strategies.

The scope of tropical forest resource problems is great relative to available capital and human resources. No single project or single organization's program is likely to sustain a substantial portion of the tropical forest resources in perpetuity. The U.S. Congress has determined that improved coordination among the various international organizations is necessary to make forestry projects more cost effective. Section 118 of the Foreign Assistance Act specifically requires the President to seek opportunities to coordinate public and private development activities and investments that affect forests in tropical countries. It also instructs U.S. representatives to multilateral organizations to promote such coordination. AID recognizes this need in its Policy Determination documents on environment and natural resources and on forestry.

AID and other development assistance organizations do keep track to some extent of what other agencies and host government departments are doing and try to develop projects accordingly. AID has participated in some important joint efforts with other international organizations. Also, the International Union for the Conservation of Nature and Natural Resources, the United Nations Environment Programme, and the World Wildlife Fund have jointly prepared a World Conservation Strategy which calls for coordinated global efforts for the conservation of natural resources. These organizations plan to coordinate their endeavors to implement the strategy.

Several regional technical centers have informal coordination roles within their area of expertise. At the country level, the United Nations Development Programme country representatives sometimes are able to assist with coordination. Still, little progress has been made in getting international organizations to work together to develop national or regional forest resource plans that would assign specific tasks to each agency.

AID and other development assistance organizations are not likely to follow a long-term plan devised by any one organization because each organization works toward its own particular objectives. Each organization's country mission has specific pressures from its central office—whether it is in Washington, Rome, or elsewhere. Many bureaucrats are under pressure to spend an exact level of funds during each fiscal year. That requires flexibility that would be constrained considerably if they had to follow a strict plan devised under the leadership of another organization.

International development assistance organizations are, however, subject to the decisions and direction of tropical nations' governments. In theory, these host governments are responsible for coordinating development assistance efforts. In practice, host governments get help from each international organization in identifying projects for that organization and there are few attempts to make the different agencies' efforts complementary.

Why do host governments not coordinate the international organizations' activities more effectively? One problem is that tropical governments need to maximize assistance funds they receive each year, even though that means accepting some projects that are poorly integrated into the nation's long-term development plans. Also, different government agencies, and individuals within agencies, have different goals. Diplomatic pressure to accept particular projects can be another problem. Finally, the development assistance organizations have little incentive to encourage tropical nations to show strong leadership.

However, if the U.S. Congress believes that close coordination of international development assistance is necessary and that achieving such coordination is worth relinquishing some degree of U.S. control over what projects are funded, Congress could mandate increased U.S. efforts to enable the tropical nations to do long-term development planning and to coordinate international assistance more effectively.

Option 4:

Congress could direct the Department of State to report on whether various tropical nations are able and politically ready to develop long-term action plans for sustained development of renewable natural resources. AID and the multilateral organizations could use these assessments as a basis for assisting tropical nations in planning and coordination.

The purpose of these assessments would be to indicate where institution-building and environmental education should be given a high priority; it would **not** be to reduce funding for nations where the political will to conserve and develop natural resource productivity is weak. Redirecting the type of aid offered could result in more cost-effective use of limited funds.

The first steps in assessing institutional capabilities for sustainable development of forest resources are being taken in AID's Environmental Profile reports. However, those reports now focus on environmental opportunities and problems primarily from a biophysical perspective and, to a lesser extent, an economic perspective. The reports suggested by this option would place more emphasis on assessing political will, values, and institutional capability. For example, does the government have effective control over logging concessionaries? Does it maintain land tenure arrangements that cause people to clear forest land that will not sustain agriculture?

The Department of State has the expertise to conduct political and economic analyses. The assessment process could be undertaken in stages, beginning with syntheses of information available in Washington, moving later to work done under the auspices of U.S. embassies.

This option has some disadvantages. Since U.S. embassies would need to make critical judgments about political willingness and capabilities, any negative statements might offend host government officials. Thus, the Department of State might be reluctant to comply rigorously. If the reports were given security classification to minimize this effect, they would be of limited use in planning development assistance activities.

Option 5:

Congress could direct the Department of State and U.S. representatives to multilateral development assistance organizations to promote international ad hoc committees formed to assist tropical nations in planning long-term forest development.

These ad hoc committees could include experts from the United States, other developed countries, and the developing countries. They would identify problems, plan a forest resource development strategy, and coordinate various assistance projects. The committees could be modeled after the Coordination for Development in Africa program (CDA).

Many benefits can be anticipated from assisting tropical nations to take increased responsibility for planning and coordination. First, if such efforts were effective, the cost effectiveness of U.S. and other nations' development assistance efforts could be improved. Effective coordination increases the probability of meeting both the necessary and sufficient conditions for sustaining tropical forest resources. Second, and perhaps most important in the long run, improved planning and coordination might encourage some tropical governments to identify and resolve the institutional constraints, such as land tenure, that inhibit development of forests and other potentially renewable resources.

Increasing tropical nations' responsibilities for planning and coordinating assistance projects may be difficult and could have some negative effects. For instance, tropical governments might have to reject some inappropriate forestry projects and the funds that go with them. This would be a hard decision politically, but such decisions are sometimes made, at least by some of the wealthier tropical nations. A greater obstacle would arise where governments do not have the necessary expertise for resource development planning. Thus, in addition to the ad hoc committees for nation-level planning, it may be necessary to provide increased support for development of local planning capabilities.

RESOURCE DEVELOPMENT PLANNING

Issue

Although resource development planning is essential for sustainable production of forest products and environmental services, the available planning technologies are seldom applied to their full potential.

Tropical governments, development assistance organizations, and private firms often make forest development decisions without sufficient planning. Unplanned forest resource use is commonly a side-effect of narrowly planned development of some other resource or other area of the forest. For example, roads are built into forest land where logging and agriculture are inappropriate. The spontaneous development that follows usually is not sustainable or economic in the long run.

There are several reasons why planning is neglected. First, government and development assistance agency decisionmakers may be unaware or unconvinced of the cost effectiveness of such planning. Second, decisionmakers may doubt that planners can provide timely results focused on relevant information and presented in understandable form. Third, many tropical countries have too little planning expertise. Fourth, domination of resource-use decisions by special interest groups can preclude comprehensive planning.

The effectiveness of planning in tropical areas is hampered by shortages of data on biophysical, social, and economic factors and by a lack of knowledge of how such factors interact. Many tropical nations need assistance to build their own capacity to produce data bases and to use them for planning. For example, improved information on biological diversity of various sites is needed to make decisions about where to locate protected areas.

Biophysical site capability and land classification are the most commonly applied components of resource development planning. These techniques are usually not well integrated with analysis of social, economic, or institutional factors. As a result, many development projects fail even though they may be suitable for the biophysical characteristics of the chosen sites.

AID is required to consider environmental impacts and has a policy requiring a "social soundness analysis" as part of project design. However, agency staff vary in their degree of cooperation with these requirements; some extend such an analysis beyond its useful bounds while others produce pro forma responses.

Option 6:

Congress could maintain the availability of low-cost Landsat images to governments in the Tropics.

Landsat images have proven useful in many tropical nations for measuring forest cover and identifying broad categories of forest types and conditions. In some instances, images taken at different times have been compared to identify rates and locations of deforestation problems. AID has had successful programs to train tropical government analysts to use Landsat imagery for resource development planning. The Landsat images have been available at low cost, but proposals to sell the U.S. satellites to private firms have been considered. Private ownership of Landsat could lead to increases in imagery prices that might discourage the use of this important tool for planning.

Resource planning can be greatly improved in many tropical nations with maps based on broad classifications of land capability. Using Landsat images, such classifications can be made rapidly and inexpensively for large areas. This is important because timeliness and expense are two of the major constraints on the use of planning analyses. Landsat is useful even where computer analysis is not available because the images can be interpreted visually. Small computers that can analyze the data in digital form are becoming more widespread in tropical nations and as a result, Landsat interpretation is becoming an even more accurate tool.

Constraints on the use of Landsat include cloud cover that consistently obscures views of some tropical areas. Many tropical governments do not yet have enough skilled personnel or facilities to use the imagery. Resource planning agencies, in some nations, cannot get images of certain forest areas because they are classified for security reasons. The major disadvantage to this option is that the U.S. Government would have to continue paying the costs of the Landsat satellites.

Option 7:

Congress could encourage AID to provide resource development planning assistance by improving the use of macrolevel land classification and the analyses of social and institutional factors in AID's "Follow-on Country Environmental Profiles." Congress could direct the U.S. representatives to international development assistance organizations to promote similar policies.

AID's Environmental Profile process is proving to be an effective mechanism for environmental education as host government agencies are becoming involved in production of the second phase of profile reports. Still, this does not guarantee that decisionmakers will consider the environmental profiles useful for development planning. Thus, it is important to proceed slowly with these activities until local interest and participation are assured. Followup is necessary so that the environmental concerns are incorporated in AID's country development strategies and in the host country's development planning.

Much technical information on natural resources in tropical forest areas already exists in the United States. It is scattered in such places as the archives of the Soil Conservation Service, the map collections of the Library of Congress, the Central Intelligence Agency, and the electronic data bases at USDA's Economic Botany Laboratory. This information can be used to produce first approximations of land-capability or life-zone maps. These could then be checked for accuracy in the subject nations, as were the first drafts of the Environmental Profiles.

Providing more pragmatic information on natural and human resource capabilities may make the reports more useful. Performing these assessments cooperatively with the host nations provides opportunities for U.S. and tropical nation personnel to gain new expertise. Cooperative production of the information also enhances the likelihood of its use outside of AID.

A number of objections to this option can be anticipated. It calls for the production of more reports not tied to specific development projects, so some tropical nations may perceive that it is an activity that only benefits AID. Preparation of such reports may be perceived by many AID and host country officials as a distraction of available time and funds.

The fact that much data on tropical forest resources gather dust in U.S. archives may indicate that many such efforts do not produce useful reports. Also, AID has sponsored biophysical land capability assessments in the past, and, when necessary, they might do so again without special prompting from the Congress. In countries where planning expertise is scarce, promotion of these techniques may be premature.

Option 8:

Congress could direct the U.S. directors of multilateral development banks to promote environmental assessments at an early stage of project planning. Congress could follow up on this request by holding periodic hearings to determine whether the banks are using environmental assessment procedures effectively.

A variety of development assistance projects affects tropical forest resources directly and indirectly. The negative effects can best be identified and mitigated at the project level because they tend to be highly site-specific. Thus, environmental quality and natural resource considerations should be integrated into the design and continuing evaluations of development projects.

For example, irrigation projects should in some cases include funding for protection of forested watersheds. The negative impacts of projects that convert tropical forest to other uses can sometimes be offset by funds to establish protected areas elsewhere. More thorough and analytical environmental review processes could increase the long-term net benefits of development projects. They also might help convince tropical governments of the importance of these factors.

The U.S. experience with environmental impact statements demonstrates the need to focus on tradeoffs that arise in decisionmaking. The U.S. process has at times been time-consuming and expensive, but it has been an effective tool for avoiding negative environmental effects. The multilateral development banks are beginning to use such procedures. The World Bank, for instance, has established an Office of Environmental Affairs. However, the environmental reviews occur late in the planning process, so the information they produce is less useful than it could be.

For the banks, it may be more desirable to integrate environmental quality and natural resource considerations into the early stages of planning than to require separate environmental impact statements. Follow-up monitoring of environmental effects during and after project implementation also deserves higher priority. However, such analyses could be pro forma and superficial if the banks and the host governments do not perceive them to be an important tool.

RESEARCH AND MARKET DEVELOPMENT

Issue (Research)

Fundamental research, applied research, and technology implementation related to tropical forests are not well coordinated. Moreover, interactions among factors that constrain forest resource development are poorly understood. Consequently, resource development projects often fail, and promising technologies too seldom spread beyond the demonstration areas. Expanded interdisciplinary research efforts in tropical forest resources are needed and these need to be more closely related to technology implementation.

Profitable technologies that can supply local people's needs and simultaneously sustain forest productivity do not exist for many types of tropical forests. Incremental improvements of existing technologies seem unlikely to accomplish these goals. Rather, new approaches in both techniques and institutions also must be invented. These must be based on improved understanding of the biological, economic, and social factors affecting forest resources. Thus, new fundamental research is needed. But forest resource degradation is occurring too rapidly for fundamental research to be conducted in the traditional, somewhat aloof fashion. Fundamental research could play a larger role in conservation and development if scientists would increase their efforts to understand the needs of applied researchers and technology users.

Interdisciplinary research on tropical forest resources has seldom been based on an adequate understanding of the needs of technology implementors. Research results often are presented in unusable formats and published in academic journals that technology implementors have little time and incentive to locate. Consequently, much applied research is not used for technology development. When it is used, there is often a time lag between completion of the research and its use.

Solutions to this problem include building more research and training components into the implementation stages of development projects and improving communication among researchers and between researchers and technology implementors. Reorganizing research efforts to improve this communication should be relatively inexpensive.

Option 9:

Congress could conduct hearings to determine 1) whether research agencies (such as the National Academy of Sciences, the National Science Foundation, and the U.S. Forest Service laboratories and institutes) are giving sufficient priority to interdisciplinary tropical forestry studies that link research and development, and 2) whether the results are being disseminated adequately. Congress could reward those agencies and programs that follow such priorities.

Hearings are a relatively inexpensive way to express congressional recognition of a need, gather information, and provide impetus to government agencies and the private sector to redirect and expand their efforts. Hearings can give recognition to individuals and programs that have taken desired actions. If hearings reveal that agencies are doing interdisciplinary research that is used to sustain tropical forest resources, Congress may choose to increase funding for those agencies.

Hearings alone, however, do not carry legislative weight. They usually require followup to affect agency behavior. Since they may reflect the interest of only a few Members of Congress, organizations may not be induced to change their priorities simply as the result of the hearing process.

Option 10:

Congress could appropriate funds specifically for UNESCO's Man and the Biosphere program.

The International Man and the Biosphere (MAB) program receives money from the general funds of UNESCO. Current levels of funding are low and much reduced from previous years. Concurrently, the Department of State support for U.S. liaison activities with the MAB program is being cut back.

MAB provides a framework for international cooperation in problem-oriented research on natural resource development. Part of its budget is earmarked for activities concerning the Tropics. Continued U.S. support for MAB would strengthen the ability of tropical nations to conduct significant research and could facilitate communication of research results to developers and users of resource-sustaining forest management technologies. In addition, it would help maintain U.S. scientists' links to this research network.

This option would require some additional funding from Congress. Moreover, increased support may not lead to improved coordination in tropical forestry research or to reorientation of research so that it addresses the real needs of technology implementors.

Option 11:

Congress could determine the feasibility of establishing agroforestry and forestry research programs at existing Consultative Group on International Agricultural Research (CGIAR) institutions.

CGIAR is a network of regional and international organizations that have experience in conducting agricultural research in developing countries and in linking research to technology implementation. The mandates of the CGIAR institutions do not include forestry and have been interpreted to exclude agroforestry as well. By developing and promoting agroforestry and forestry systems, CGIAR research could help alleviate pressures to convert remaining tropical forests to other uses.

The addition of forestry or agroforestry programs to these institutions could facilitate interdisciplinary research cooperation and the development of production systems in which agriculture and forestry are integrated. Capital outlay would be minimal because the network and institutional infrastructure already exist.

Adding such programs would involve internal adjustments and priority shifts within and between existing institutions, so the CGIAR institutions might resist an attempt to incorporate forestry or agroforestry unless substantial additional funding were provided. Even with additional funds the changes might be disruptive for CGIAR institutions, many of which are oriented not to farming systems but rather to production of particular agricultural commodities.

Option 12:

Congress could amend existing legislation that allocates funds for tropical agriculture activities to include tropical forestry and agroforestry explicitly. To do so would improve the likelihood that forestry, agroforestry, and conventional crop production would be viewed as complementary activities.

Some forestry activities take place under agricultural programs. For example, Public Law 480 funds have been used occasionally to support reforestation, and a few forestry schools have been awarded Title XII grants where "agriculture" has been interpreted broadly. However, without specific reference to tropical forestry and agroforestry, important opportunities to apply techniques that can sustain resource productivity may be lost.

Congress could amend Public Law 480, the Food for Peace Act of 1966 (specifically sec. 406(a) 2 and 4) so that "agriculture" explicitly includes **forestry and agroforestry.** Similarly, Congress could broaden Title XII of the Foreign Assistance Act (specifically sec. 211(d)), which awards grants to help solve critical food problems of the developing world, to increase involvement by U.S. forestry schools and other appropriate government agencies. These expanded mandates could be supported by diverting money from other development activities or by allocating new moneys through existing institutions.

Broadening existing agricultural funding mechanisms to include forestry and agroforestry avoids overhead expenses that would occur if new programs were created. It also would help promote a much needed interdisciplinary approach to deal with problems of tropical land use.

The major argument against amending existing legislation would be that such an action might hinder the achievement of other goals by diluting limited funds and personnel. Many experts believe that substantially more funds will be necessary to advance agroforestry and forestry significantly. Another problem is that even with explicit direction from Congress, the institutions committed to agriculture may continue to give forestry and agroforestry only a small share of their resources.

Option 13:

Congress could establish a trust fund for the Forestry Department of FAO to support improved communication among researchers and technology implementors.

FAO has the world's largest accumulation of professional tropical forestry expertise. The organization has strong connections to tropical governments, tropical forestry experts, and both multilateral and bilateral development assistance agencies. FAO's activities include creating a world forest resource information system and promoting social forestry. It publishes a forestry journal, *Unasylva*, and series of technical forestry papers. FAO has been instrumental in focusing world attention on the need to integrate forestry into community development.

The U.S. contribution to FAO goes into a general fund; FAO then allocates portions to its various programs. Forestry receives only a small share and the United States has a relatively minor role in FAO's Forestry Department. A trust fund is a way to ensure that the forestry program receives additional money and to enhance opportunities for use of U.S. expertise on tropical forests.

A trust fund also would permit the United States to negotiate some particular priorities for funding. For example, the United States could establish a trust fund specifically to support interdisciplinary research components in FAO forestry development projects and to enhance the communication of research results and technical information. Such a trust fund might support management training programs or the preparation, publication, and dissemination of forestry information in appropriate languages for technical schools and practitioners.

However, FAO may not be the best place to invest U.S. funds intended to support technologies to sustain tropical forest resources. This would require additional funds beyond the current statutory limits on the U.S. contribution to FAO. The United States has not had a strong voice at FAO planning sessions for regular forestry activities. Finally, political benefits to the United States from funds spent through a multilateral agency may be less than political benefits from a U.S. bilateral agency.

Option 14:

Congress could amend the Foreign Assistance Act (sec. 301, U.S. Voluntary Contributions to U.N. Organizations) to include funding for the United Nations University (UNU).

UNU functions through and strengthens networks of existing universities and research institutions around the world. It provides a variety of courses, instructors, and research facilities. It is an international community of scholars engaged in interdisciplinary research, post-graduate training, and dissemination of knowledge to international organizations, governments, scholars, policymakers, and the public. The U.S. Government has never provided financial support to UNU. The main advantage of such a contribution would be promotion of interdisciplinary research.

The main objections to this option are that it requires increased Federal spending and that funds might be used more efficiently by the U.S. National Science Foundation or by AID's technology transfer programs.

Issue (Product and Market Development)

Sustaining forests in many tropical areas will depend on developing markets for local forest products. Many products that are gathered on a subsistence basis do not attract investment for sustainable development because they appear to be 'free.' Furthermore, government agencies are often unaware of the forest's potential to support rural development.

Tropical forest ecosystems house complex associations of vegetation, wildlife, and other potential resources, some of which could be developed as commodities profitable to harvest on a managed basis. Information gathered on noncommercial tree species and nonwood forest products is abundant. But it seldom includes more than taxonomic identification and a brief discussion of existing product uses by tropical people. Developing markets for unused or underused forest products could motivate local people and development agencies to invest time and capital in managing forest resources. Thus, in some areas, product and market development could be a way to maintain biological diversity and simultaneously provide profitable rural development.

Option 15:

a) Congress could mandate and fund the U.S. Forest Products Laboratory to develop new products and market information for tropical forest resources and to increase its efforts tc transfer the technologies.

b) Congress could direct AID to expand its support for dissemination of information on underused tropical forest resources and to pursue market development for those products that are sustainable with the kinds of management likely to occur.

Using a wider range of tree species and sizes should make intensive management of smaller forest areas feasible and profitable. This would allow larger harvests from smaller areas, protecting biological diversity in unharvested areas while providing materials for export or local development. Use of many tree species and sizes can supply growing domestic markets and at the same time continue to produce wood for export markets. Logging from smaller areas would also make enforcement of strict regulations regarding road engineering, site protection, and restoration of the forest more feasible.

The U.S. Forest Products Laboratory is conducting some research on tropical wood product use, and several of its projects for temperate zone forestry are producing technologies that can be used in the Tropics. A more specific congressional mandate and additional funding would ensure continuation and expansion of such activities and could enhance technology transfer to tropical areas.

Additional knowledge of the role of forest products in subsistence economies and improved development of markets for nonwood forest products could cause decisionmakers to value forests more highly. More support could be developed for local forestry investments and conservation efforts. Development of production systems and markets for nonwood tropical forest resources could provide employment and income-generating activities for rural people while reducing incentives to convert forest to unsustainable land uses.

AID has considerable experience with production system and market development for agricultural products and this could be applied to tropical forest products. Furthermore, AID could increase its support for the BOSTID project that synthesizes, publishes, and distributes information on underexploited tropical resources. This relatively inexpensive project already has been very effective in stimulating investment in such resource development.

Several constraints hold back development of new forest products. Even if research were increased, it is not clear that the potential new products would attract investment. One problem is that inexpensive and reliable screening techniques for evaluating potential forest products have not been developed. Another problem is that market research for new products often must depend on unverified assumptions about what the product price will be and on unreliable consumer preference surveys. Also, in many tropical countries capital earns high rates of return and entrepreneurial talent is highly rewarded in enterprises less risky than new product development. Furthermore, information on traditional uses of minor forest products is difficult to collect.

Successful product and market development should lead to higher profits from forest resource harvesting. If governments do not make simultaneous investments in forest management and in regulation and control of those who harvest the resources, however, market development could lead to more rapid depletion of the resources.

BIOLOGICAL DIVERSITY

Issue

Benefits from preserving biological diversity of tropical forests accrue to society as a whole, including future generations, yet the costs are borne by the present generation in tropical countries.

Tropical forests are great reservoirs of biological diversity. They contain some 2 million species of plants and animals. But diverse forest ecosystems generally do not produce high yields per hectare per year of highly valued products. So development usually entails replacing diverse systems with simpler ones.

Natural forests can be modified to make them economically productive while maintaining significant biological diversity. However, for many types of forests this will not occur until more profitable management technologies are developed. For now, the full original species composition of tropical forests probably can be preserved only in areas that remain inaccessible or in areas set aside for research, education, and recreation.

Maintenance of some natural forest ecosystems can be justified because they are on steeply sloping watershed catchments. Cloud forests are an example. For now, however, investments in protection and maintenance of other biologically diverse natural forests will have to be motivated by recognition of the potential these areas and the genetic resources they contain hold for future generations.

Option 16:

Congress could conduct hearings on its recent amendment to the Foreign Assistance Act which directs AID, in concert with other appropriate agencies, to develop a comprehensive U.S. strategy to maintain biological diversity. Congress also could encourage U.S. representatives to multilateral organizations to promote similar strategies.

Over the past 5 years, AID, the World Bank, and some other assistance organizations have developed strategies for investing in forest resources (mainly to produce wood) and for ameliorating the negative environmental effects of development projects. The process of developing and implementing these strategies has helped educate decisionmakers about environmental consequences of economic development projects and about new approaches to forestry. The strategies have begun to foster more sustainable development projects.

The strategy to support biological diversity can be expected to have a similar effect. If conservation of biological diversity were made an explicit goal for development projects, development agencies would act to keep open future options for development of renewable resources. This eventually could lead to new ways of using and sustaining these resources to meet basic human needs or to produce biological products for export. Maintaining biological diversity can complement sustainable economic development because it fosters environmental stability and renewable resource productivity.

Some AID officials may be reluctant to comply rigorously with the intent of the amendment. It may be perceived as another restriction that hinders AID and other development assistance organizations. Actions will not necessarily stem from the strategy unless there is strong commitment and support within the agencies.

Option 17:

Congress could support the creation of an international fund to subsidize the establishment and maintenance of protected areas in the Tropics.

Although there are many designated protected areas in the Tropics, most receive little protection and many are being deforested or degraded. Often this is because poor nations can not afford the costs of adequate protection. Various ways to finance protected areas have been suggested. One proposal is to solicit contributions from developed countries or to tax some internationally traded commodities to create an international fund. The fund would provide grants to tropical nation governments to establish and manage protected areas. Another suggestion is for the assistance agencies to finance an international fund that would support a wide variety of development projects outside the forests. These would be designed to reduce the motivation for exploiting the protected areas. The fund would support such projects as compensation for the direct and indirect costs of protected areas. (Indirect costs include the foreign exchange and income foregone as a result of restrictions on harvesting forest products.)

Creating a major fund for tropical forest protected areas would increase opportunities to preserve these habitats and their vast biological diversity. The fund would make additional moneys available for parks where and when most needed. Some money is available for protected area establishment from scattered sources, but it is not sufficient and is rarely available to manage existing protected areas.

This option is likely to be expensive. The tropical forests to be protected are often in remote areas. The logistics of both policing the protected areas and creating suitable economic development opportunities for people outside the protected areas would be difficult. Furthermore, the suggested funding mechanisms may face serious objections. International funds for work on environmental problems, such as desertification, have not had much success in soliciting contributions from developed nation governments. Taxes on forest products would raise consumer prices in importing countries and reduce revenues to tropical countries. Diverting funds from existing development assistance activities could have adverse effects on those activities.

U.S. EXPERTISE

Issue

U.S. expertise on tropical forest resources is widely scattered and is not being developed or used effectively.

Tropical governments and international organizations are beginning to increase investments in tropical forest resources. As a result, demands for U.S. technical and financial support are increasing. The United States has few well-qualified, experienced experts on tropical forest resources and has limited funds to allocate to this field of growing importance. Nonetheless, U.S. expertise is recognized in fields that include reforestation, watershed management, forest industries, resource inventory and mapping, resource development planning, information processing, botany, zoology, and environmental education. Furthermore, the United States has a wide variety of public and private organizations that could contribute to an expanded international program on tropical forests. Much more could be done to create opportunities for U.S. expertise to help sustain tropical forests.

U.S. science and technology alone cannot be sufficient to sustain tropical forests because of the scale of the problem and because most of the tropical forests are the sovereign resources of foreign nations. In the long term, science and technology expertise must come from within the tropical countries. However, U.S. expertise is needed now both to assist directly with technology development and implementation and to build indigenous scientific and technical capabilities in tropical nations.

Option 18:

Congress could modify the organic legislation for those U.S. agencies* whose actions affect forest resources in tropical nations and U.S. tropical territories. The amendments would state in substance that the agencies, in their regular activities: 1) will not contribute to or fund conversion or degradation of tropical forests unless such activities are preceded by detailed resource development plans indicating that the conversion will result in sustainable land use, and 2) will act to maintain and enhance tropical forest resources and act to slow or stop deforestation and degradation.

Ensuring that the Federal agencies do not contribute to the unsustainable use of tropical forest resources would be a significant first step. Federal agencies also could do a great deal to help develop and use resource-sustaining technologies. Such a mandate from Congress would signal the importance of maintaining tropical forests and the species they contain while developing them to benefit those who rely on their products and services for livelihood.

The U.S. National Park Service, Fish and Wildlife Service, and Forest Service have international offices, but their responsibilities are not well-defined in the organic legislation. For example, the National Park Service's organic legislation could be amended to direct that agency to share its expertise in protected area establishment, management, and related training with tropical countries. The Forest Service's institutes in Puerto Rico and Hawaii could be directed to provide research and training in response to tropical nation needs. In addition, various agencies might provide more opportunities for foreign resource managers to receive training.

One disadvantage of this option is that expanded mandates might conflict with existing interests and abilities in some agencies. Thus, the changes might not receive support from agencies that perceive them as hindering their abilities to function effectively, especially if significant staff time is taken from other responsibilities. In addition, more funds and staff might be needed, depending on how the mandate is implemented.

Option 19:

Congress could request the General Accounting Office to determine how Federal agencies are using existing legislation enabling Federal employees with appropriate expertise to work in international assistance agencies, American embassies, and international nongovernmental organizations. Where appropriate, Congress could hold hearings, update or amend existing legislation, and direct the Office of Personnel Management to encourage the use of those laws.

Mechanisms exist that enable U.S. Government personnel to work on such problems as tropical deforestation. To determine if this is occurring, GAO could review the agencies' use of the Federal Employees International Service Act, the Intergovernmental Personnel Act, and appropriate Executive Orders in the Federal Personnel Manual (e.g., Executive Order No. 11552 of Aug. 24, 1970, enables details and transfers of Federal employees to international organizations).

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*Government organizations concerned with tropical forests include the Department of State, Agency for International Development, Council on Environmental Quality, Department of Agriculture, U.S. Forest Service, Industry and Trade Administration, National Oceanic and Atmospheric Administration, Bureau of Land Management, Fish and Wildlife Service, National Park Service, International Development Cooperation Agency, National Aeronautics and Space Administration, National Science Foundation, Peace Corps, Smithsonian Institution, Department of Defense, Corps of Engineers, International Executive Service Corps, Overseas Private Investment Corporation, Export-Import Bank, and Trade and Development Program.

Updating or simply calling attention to these mechanisms for overseas work may encourage Federal employees to work on tropical forestry issues. This would help build a cadre of experienced U.S. tropical forest resource experts to support future U.S. tropical forestry initiatives.

Legislation alone may not be enough to increase substantially the participation of U.S. forest resource experts overseas. To date, involvement of U.S. resource managers abroad has been limited by absence of long-term career opportunities. In fact, agencies may discourage staff participation in international programs. Federal agencies, already short on staff, are reluctant to let personnel go abroad. Thus, employees who do work overseas commonly are in the early stages of their careers or are nearing retirement. It may be necessary for Federal agencies to re-examine their reward structures and ensure re-entry to responsible positions upon participants' return to the United States.

Option 20:

Congress could encourage the U.S. private sector to develop and implement technologies that sustain tropical forest resources.

Congress could encourage the Overseas Private Investment Corporation (OPIC) and the Trade and Development Programs under the International Development Cooperation Agency (IDCA) to give special help to U.S. firms that have technologies appropriate for maintaining and enhancing tropical forest resources. OPIC and IDCA could help such firms establish or expand operations in tropical nations. In addition, Congress could amend the Foreign Assistance Act to direct AID mission directors to give such firms a preferred status in procurement of technologies, products, or services. This incentive in conjunction with OPIC assistance might expedite transfer of resource-sustaining U.S. technology to tropical nations.

Another law that might be modified is the Small Business Innovation Research Act, which at present does not require AID's compliance. In addition, the International Executive Service Corps could devote more effort to recruiting volunteer retired executives with expertise in managing natural resources. Further opportunities to influence the private sector could be identified from congressional hearings.

A wealth of information, technology, and expertise that could be used to help tropical nations resides within the private sector. U.S. firms could stimulate investment in forest resource conservation and development, and, as a consequence, the United States could benefit from more reliable sources of goods and from new investment opportunities. The private sector can be more efficient than government in technology research, development, and implementation.

Reinvestment of profits into projects in developing countries, especially joint ventures, is one important mechanism for technology transfer. Another is private sector exchange programs, including on-the-job instruction in the United States, consulting, onsite workshops and training programs, support of local scientific and educational institutions, serving as guest instructors at foreign universities or management institutes, and sponsoring attendance of developing country personnel at international symposia and conferences.

Increased involvement of the U.S. private sector could cause some problems, however. U.S. private businesses might displace or stifle growth of some indigenous private businesses in the forestry sector. Markets might collapse or infrastructure might not be maintained when U.S. firms leave a tropical area. In addition, most resource-sustaining ventures involve long-term commitments of capital which many private businesses may be unwilling to risk in potentially unstable developing countries, even with OPIC insurance. Finally, U.S. businesses are not required to perform environmental impact assessments overseas and may cause unintended damage to tropical forest resources.

Option 21:

Congress could authorize U.S. participation in the United Nations Associate Experts Program.

Under the U.N. Associate Experts program, developed countries send technical personnel to developing countries to work on U.N. agency projects, including forestry and rural development projects. The developed country pays the salary of its own experts. The United States does not participate in this program, although most OECD countries do. U.S. participation might be administered through existing offices of the Peace Corps or the Forest Service.

U.S. participation in the Associate Experts program could have advantages for both the U.S. and the tropical nations. U.S. participants would be able to transfer technical and managerial skills needed for resolving practical forestry problems in the Tropics. This program also would increase the visibility of the U.S. role in tropical forestry and facilitate scientific and cultural interchange between Americans and decisionmakers in tropical countries.

The United States has few opportunities to develop tropical forestry expertise beyond the level acquired by Peace Corps volunteers. This is one reason why few Americans work on forestry projects administered by FAO and other multilateral development organizations. Participation in the Associate Experts program would give U.S. experts the needed opportunities to acquire tropical experience. Thus, it should lead to a greater role for U.S. citizens in international agencies and increased marketability of U.S. consulting services abroad.

Since this would be a new program for the United States, new funding would be required. Only a small number of qualified U.S. experts may be available for participation in this program. To some extent, the Associate Experts program may overlap with bilateral programs of U.S. AID and other agencies.

Option 22:

Congress could designate U.S. centers of excellence to focus U.S. expertise on tropical forest resources and provide opportunities for research, education, and technology transfer.

Effective use and further development of United States tropical forestry expertise are constrained by a lack of institutions in which tropical forests are an issue of prime importance. The U.S. experts with knowledge and experience needed for sustainable development of tropical forest resources are scattered among public, private, and academic institutions. The experts have too few opportunities to practice or improve their expertise or to provide fieldwork for students. Development assistance agencies, private firms, and organizations working with forest resources in tropical countries have difficulty locating expert scientists. Much of the work by U.S. experts is terminated before it succeeds because institutional continuity is lacking.

Centers of excellence could address many of these faults. They could organize education curricula and research programs that integrate social, physical, and biological perspectives. They could establish strong links between fundamental and applied researchers and communication between researchers and technology implementors. They could act as brokers of information and expertise by directing tropical governments, tropical universities and students, and assistance agencies by directing them to appropriate U.S. experts. Also, they could help U.S. experts and students locate private firms, tropical universities, or government agencies interested in collaborative work, and by identifying sources of funding for these kinds of exchanges.

Centers of excellence in tropical forestry could be established to correspond to each geographic region of the tropical world (tropical America, Asia, and Africa), or centers could be organized according to ecological categories (dry open forest, moist closed forest, mountain forest). Possible locations for such centers include the U.S. Forest Service's Institute of Tropical Forestry in Puerto Rico (perhaps in conjunction with the USDA Mayaguez Institute of Tropical Agriculture and the University of Puerto Rico), the U.S. Forest Service's Institute of Pacific Islands Forestry (in conjunction with the University of Hawaii and the East/West Center), or the Klieberg Institute at Texas A&I University (in conjunction with other departments of that university).

Locating centers for tropical forestry excellence in U.S. tropical or semiarid environments would have important advantages. Research, demonstration, and education field work could be conducted on technologies appropriate for the biophysical conditions that prevail in tropical regions. The centers could be expected to get more support from local organizations than if they were located at U.S. sites where their work had no local applicability. Centers in the United States would be accessible to the U.S. experts and students who are scattered among many organizations. This accessibility would be most important for the expertise brokering function.

There are several arguments against this option. First is the problem of funding. Developing the institutes in Puerto Rico and Hawaii as centers of excellence in tropical forestry would require significant changes in the Forest Service budget. Another problem is that many of the ecological, institutional, social, and economic conditions typical of the tropical nations do not occur on the U.S. tropical islands or semiarid sites. Institutes located in tropical nations would be more accessible to indigenous tropical scientists and students and so might be more effective in supporting the tropical nation's own institutions. Another problem is that centers of excellence, whether located in the U.S. or tropical nations, might focus too narrowly on technical issues and biophysical sciences, thus neglecting institutional and social issues that are fundamental constraints on forest development and conservation in tropical countries.

Appendixes

Appendix A

Status of Tropical Forests: Tables

Table A-1.—Closed Forests in Tropical Africa, America, and Asia, 1980 (thousands of hectares)

Country	Total area	Closed forest area	Percent of total
Tropical Africa:			
Zaire	226,760	105,750	46.6
Congo	34,200	21,340	62.4
Gabon	26,767	20,500	76.6
Cameroon	47,544	17,920	37.7
Madagascar	59,099	10,300	17.4
Nigeria	92,377	5,950	6.4
Ivory Coast	32,246	4,458	13.8
Ethiopa	122,190	4,350	3.6
Central African Republic	62,298	3,590	5.8
Zambia	75,261	3,010	4.0
Angola	124,670	2,900	2.3
Guinea	24,586	2,050	8.3
Liberia	9,632	2,000	20.8
Ghana	23,854	1,718	7.2
Somalia	63,754	1,540	2.4
Tanzania	93,970	1,440	1.5
Equatorial Guinea	2,806	1,295	46.2
Kenya	58,037	1,105	1.9
Mozambique	78,303	935	1.2
Uganda	19,684	765	3.9
Sierra Leone	7,333	740	10.1
Guinea-Bissau	3,613	660	18.3
Sudan	250,581	650	0.3
Chad	128,400	500	0.4
Togo	5,680	304	5.4
Senegal	19,672	220	1.1
Zimbabwe	38,936	200	0.5
Malawi	11,858	186	1.6
Rwanda	2,634	120	4.6
Gambia	1,040	65	6.2
Benin	11,262	47	0.4
Burundi	2,783	26	0.9
Botswana	57,500	[a]	[a]
Namibia	82,429	[a]	[a]
Upper Volta	27,420	[a]	[a]
Niger	126,700	[a]	[a]
Mali	120,383	[a]	[a]
Total	2,176,279	216,634	10.0
Tropical America:			
Brazil	851,196	357,480	42.0
Peru	128,522	69,680	54.2
Colombia	113,889	46,400	40.7
Mexico	196,718	46,250	23.5
Bolivia	109,858	44,010	40.1
Venezuela	91,205	31,870	34.9
Guyana	21,497	18,475	85.9
Surinam	16,382	14,830	90.5
Ecuador	27,067	14,250	52.6
French Guiana	9,100	8,900	97.8
Nicaragua	13,000	4,496	34.6
Guatemala	10,889	4,442	40.8
Panama	7,708	4,165	54.0
Paraguay	40,675	4,070	10.0
Honduras	11,209	3,797	33.9
Costa Rica	5,090	1,638	32.2
Cuba	11,450	1,455	12.7
Belize	2,297	1,354	59.0
Dominican Republic	4,840	629	13.0
El Salvador	2,099	141	6.7
Jamaica	1,142	67	5.9
Haiti	2,775	48	1.7
Trinidad and Tobago	513	208	40.6
Total	1,679,121	678,655	40.4
Tropical Asia:			
Indonesia	191,930	113,895	59.3
India	328,700	51,841	15.8
Papua New Guinea	46,170	34,230	74.1
Burma	67,658	31,941	47.2
Malaysia	33,008	20,995	63.6
Philippines	29,940	9,510	31.8
Thailand	51,352	9,235	18.0
Viet Nam	33,433	8,770	26.2
Laos	23,680	8,410	35.5
Kampuchea	18,104	7,548	41.7
Pakistan	80,519	2,185	2.7
Bhutan	4,660	2,100	45.1
Nepal	14,080	1,941	13.8
Sri Lanka	6,558	1,659	25.3
Bangladesh	14,400	927	6.4
Brunei	577	323	56.0
Total	944,769	305,510	32.3

[a] No data; in most cases this is where the areas are very small.

SOURCE: Food and Agriculture Organization/United Nations Environment Programme, *Tropical Forest Resources Assessment Project (GEMS): Tropical Africa, Tropical Asia, Tropical America,* 4 vols. (Rome: 1981).

Table A-2.—Condition of Closed Forests in Tropical Africa, America, and Asia, 1980

Country	Undisturbed (%)	Logged (%)	Managed (%)	Physically unproductive (%)	Parks and protected areas
Tropical Africa:					
Zaire	75	a	a	19	5
Congo	48	16	a	35	1
Gabon	52	45	a	3	a
Cameroon	39	55	a	5	a
Madagascar	16	49	a	26	9
Nigeria	6	44	a	50	a
Ivory Coast	4	69	a	12	15
Ethiopia	15	23	a	62	a
Central African Republic	87	10	a	3	a
Zambia	11	65	a	16	7
Angola	0	84	a	16	a
Guinea	56	15	a	29	a
Liberia	45	21	a	34	a
Ghana	a	9	68	a	23
Somalia	a	6	a	94	a
Tanzania	17	40	a	14	28
Equatorial Guinea	61	18	a	22	a
Kenya	22	16	6	4	52
Mozambique	7	41	a	49	3
Uganda	13	16	58	5	8
Sierra Leone	a	30	a	70	a
Guinea-Bissau	54	11	a	36	a
Sudan	a	45	8	47	a
Chad	100	a	a	a	a
Togo	15	68	a	17	a
Senegal	6	a	a	65	29
Zimbabwe	a	a	a	100	a
Malawi	a	22	a	a	78
Rwanda	a	47	a	40	13
Gambia	a	8	a	92	a
Benin	30	70	a	a	a
Burundi	a	23	a	15	62
Botswana	a	a	a	a	a
Namibia	a	a	a	a	a
Upper Volta	a	a	a	a	a
Niger	a	a	a	a	a
Mali	a	a	a	a	a
Total	55	20	1	20	4
Tropical America:					
Brazil	81	3	a	15	1
Peru	54	9	a	36	1
Colombia	83	2	a	10	5
Mexico	28	25	a	47	1
Bolivia	40	27	a	32	a
Venezuela	24	36	a	26	14
Guyana	66	7	a	27	a
Surinam	81	3	a	12	4
Ecuador	76	1	a	21	2
French Guiana	84	2	a	15	a
Nicaragua	80	5	a	9	a
Guatemala	27	41	a	31	1
Panama	51	20	a	29	a
Paraguay	14	61	a	23	2
Honduras	21	57	2	20	a
Costa Rica	20	47	a	13	20
Cuba	a	55	14	32	a
Belize	a	66	a	34	a
Domincan Republic	38	53	a	9	a
El Salvador	a	18	a	82	a
Jamaica	61	6	a	30	3
Haiti	19	33	a	48	a
Trinidad and Tobago	a	64	7	29	a
Total	67	10	a	21	2

Table A-2.—Condition of Closed Forests in Tropical Africa, America, and Asia, 1980—Continued

Country	Undisturbed (%)	Logged (%)	Managed (%)	Physically unproductive (%)	Parks and protected areas
Tropical Asia:					
Indonesia	34	31	a	30	5
India	12	8	63	4	13
Papua New Guinea	40	1	a	59	a
Burma	46	18	11	24	1
Malaysia	36	26	12	21	5
Philippines	32	41	a	20	7
Thailand	50	a	a	26	24
Viet Nam	18	25	1	50	6
Laos	43	a	a	57	a
Kampuchea	61	11	a	28	a
Pakistan	19	10	19	51	1
Bhutan	57	30	a	13	a
Nepal	46	20	a	18	17
Sri Lanka	1	73	a	14	12
Bangladesh	5	1	86	3	6
Brunei	84	5	a	10	1
Total	33	20	13	28	6

[a] No data; in most cases this is where the areas are very small.

SOURCE: Food and Agriculture Organization/United Nations Environment Programme, *Tropical Forest Resources Assessment Project (GEMS): Tropical Africa, Tropical Asia, Tropical America*, 4 vols. (Rome: 1981).

Table A-3.—Open Forest and Shrubland in Tropical Africa, America, and Asia, 1980 (thousands of hectares)

Country	Open forest	Percent of total area	Shrubland	Percent of total area
Tropical Africa:				
Zaire	71,840	31.7	11,300	5.0
Angola	50,700	40.7	16,150	13.0
Sudan	47,000	18.8	87,000	34.7
Tanzania	40,600	43.2	13,800	14.7
Botswana	32,560	56.6	20,000	34.8
Central African Republic	32,300	51.8	7,000	27.3
Zambia	26,500	35.2	3,200	4.2
Ethiopia	22,800	18.7	25,000	20.5
Zimbabwe	19,700	50.6	900	2.3
Namibia	18,420	22.3	37,315	45.3
Mozambique	14,500	18.5	29,000	37.0
Chad	13,000	10.1	9,750	7.6
Senegal	10,825	55.0	1,365	6.9
Nigeria	8,800	9.5	36,800	39.8
Mali	8,800	7.3	6,000	5.0
Guinea	8,600	35.0	7,000	28.5
Cameroon	7,700	16.2	9,500	20.0
Somalia	7,510	11.8	53,000	83.1
Upper Volta	7,200	26.3	3,000	10.9
Ghana	6,975	29.2	300	1.3
Ivory Coast	5,376	16.7	60	0.2
Uganda	5,250	26.7	100	0.5
Malawi	4,085	34.4	380	3.2
Benin	3,820	33.9	3,075	27.3
Madagascar	2,900	4.9	4,000	6.8
Niger	2,900	2.3	6,000	4.7
Guinea-Bissau	1,445	40.0	17	0.5
Togo	1,380	24.3	2,265	39.9
Sierra Leone	1,315	17.9	3	a
Kenya	1,255	2.2	37,500	64.6
Gambia	150	14.4	360	34.6
Rwanda	110	4.2	90	3.4
Gabon	75	0.3	a	a
Liberia	40	0.4	100	1.0
Burundi	14	0.5	a	a
Congo	a	a	1,400	4.1
Equatorial Guinea	a	a	10	0.4
Total	486,445	22.4	442,740	20.3
Tropical America:				
Brazil	211,200	24.8	61,200	7.2
Paraguay	28,640	70.4	a	a
Bolivia	24,700	22.5	9,000	8.2
Colombia	5,700	5.0	5,500	4.8
Venezuela	3,300	3.6	2,120	2.3
Mexico	2,100	1.1	59,500	30.3
Peru	1,120	0.9	3,150	2.4
Surinam	690	4.2	200	1.2
Ecuador	550	2.0	1,050	3.9
Honduras	200	1.8	1,220	10.9
Costa Rica	160	3.1	120	2.4
Guatemala	100	0.9	1,505	13.8
Belize	92	4.0	46	2.0
French Guiana	70	0.8	7	0.1
Guyana	25	0.1	115	0.5
Haiti	a	a	53	1.9
Dominican Republic	a	a	54	1.1
Nicaragua	a	a	210	1.6
Panama	a	a	a	a
Jamaica	a	a	227	19.9
Trinidad and Tobago	a	a	6	1.2
Cuba	a	a	305	2.7
El Salvador	a	a	293	14.0
Total	278,647	16.6	145,881	8.7
Tropical Asia:				
Thailand	6,440	12.5	500	1.0
India	5,393	1.6	5,378	1.6
Laos	5,215	22.0	735	3.1
Kampuchea	5,100	28.2	400	2.2
Papua New Guinea	3,945	8.5	85	0.2
Indonesia	3,000	1.6	23,900	12.4
Viet Nam	1,340	4.0	330	1.0
Pakistan	295	0.4	1,105	1.4
Nepal	180	1.3	230	1.6
Bhutan	40	0.9	25	0.5
Malaysia	a	a	a	a
Philippines	a	a	a	
Brunei	a	a	a	a
Sri Lanka	a	a	215	3.3
Burma	a	a	2,600	3.8
Bangladesh	a	a	a	a
Total	30,948	3.3	35,503	3.8

[a] No data; in most cases this is where the areas are very small.

SOURCE: Food and Agriculture Organization/United Nations Environment Programme, *Tropical Forest Resources Assessment Project (GEMS): Tropical Africa, Tropical Asia, Tropical America*, 4 vols. (Rome: 1981).

Table A-4.—Forest Fallow† in Tropical Africa, America, and Asia, 1980 (thousands of hectares)

Country	Forest fallow	Ratio of forest fallow to closed forest
Tropical Africa:		
Sierra Leone	3,860	5.2
Ghana	6,500	3.8
Liberia	5,500	2.8
Ivory Coast	8,400	1.9
Angola	4,850	1.7
Nigeria	7,750	1.3
Sudan	600	0.9
Equatorial Guinea	1,165	0.9
Togo	250	0.8
Guinea	1,600	0.8
Mozambique	500	0.5
Burundi	14	0.5
Zambia	900	0.3
Cameroon	4,900	0.3
Madagascar	3,500	0.3
Guinea-Bissau	170	0.3
Rwanda	25	0.2
Benin	7	0.2
Tanzania	100	0.1
Gabon	1,500	0.1
Zaire	7,800	0.1
Central African Republic	300	0.1
Congo	1,100	0.1
Ethiopia	300	0.1
Kenya	55	0.1
Uganda	a	a
Somalia	a	a
Zimbabwe	a	a
Botswana	a	a
Namibia	a	a
Malawi	a	a
Chad	a	a
Gambia	a	a
Mali	a	a
Niger	a	a
Senegal	a	a
Upper Volta	a	a
Total	61,646	0.3
Tropical America:		
Jamaica	159	2.4
Haiti	43	0.9
Paraguay	3,270	0.8
Mexico	26,000	0.6
Cuba	700	0.5
Dominican Republic	267	0.4
Belize	525	0.4
Venezuela	10,650	0.3
Trinidad and Tobago	57	0.3
Nicaragua	1,370	0.3
Colombia	8,500	0.2
Ecuador	2,350	0.2
Honduras	680	0.2
El Salvador	22	0.2
Peru	5,350	0.1
Brazil	46,420	0.1
Guatemala	360	0.1
Costa Rica	120	0.1
Surinam	270	a
Bolivia	1,100	a
French Guiana	75	a
Guyana	200	a
Panama	124	a
Total	108,612	0.2
Tropical Asia:		
Viet Nam	10,750	1.2
Brunei	237	0.7
Laos	5,000	0.6
Burma	18,100	0.6
Sri Lanka	853	0.5
Philippines	3,520	0.4
Bangladesh	315	0.3
Malaysia	4,825	0.2
India	9,470	0.2
Indonesia	13,460	0.1
Thailand	800	0.1
Nepal	110	0.1
Bhutan	205	0.1
Papua New Guinea	1,380	a
Kampuchea	200	a
Pakistan	a	a
Total	69,225	0.2

[a] No data; in most cases this is where the areas are very small.

†Forest fallow is land that has been cleared for cultivation and subsequently abandoned so that it may again have woody vegetation.

SOURCE: Food and Agriculture Organization/United Nations Environment Programme, *Tropical Forest Resources Assessment Project (GEMS): Tropical Africa, Tropical Asia, Tropical America*, 4 vols. (Rome: 1981).

Table A-5.—Forest Plantations in Tropical Africa, America, and Asia, 1980

Country	Total land area (1,000 ha)	Area of plantations (ha)	Industrial plantations (%)	Nonindustrial plantations (%)
Tropical Africa:				
Madagascar	58,693	266,000	42	58
Sudan	250,658	187,850	31	69
Kenya	58,272	180,900	87	13
Nigeria	92,361	163,300	90	10
Angola	124,680	157,200	43	57
Zimbabwe	38,936	100,250	71	29
Ethiopia	122,187	98,200	1	99
Tanzania	94,239	97,750	69	31
Malawi	11,847	80,300	97	3
Ghana	23,856	75,250	35	65
Uganda	23,607	45,700	30	70
Ivory Coast	32,243	44,900	84	16
Zambia	75,261	38,000	88	12
Rwanda	2,635	29,000	12	88
Mozambique	78,311	25,400	63	37
Zaire	234,628	22,500	84	16
Burundi	2,721	19,500	33	67
Gabon	26,766	19,000	63	37
Benin	11,261	19,000	41	59
Cameroon	47,541	18,500	56	44
Congo	34,199	16,800	100	0
Senegal	19,671	12,500	28	72
Upper Volta	27,418	12,000	0	100
Togo	5,685	11,300	67	33
Somalia	63,732	11,000	0	100
Liberia	11,135	6,300	100	0
Niger	126,638	6,000	0	100
Sierra Leone	7,334	5,800	91	9
Chad	128,449	3,200	0	100
Guinea	23,852	2,850	75	25
Mali	120,383	1,900	11	89
Gambia	1,040	1,300	100	0
Central African Republic	62,298	500	0	100
Guinea-Bissau	3,613	350	86	14
Namibia	82,416	300	100	0
Botswana	57,496	[a]	—	—
Equatorial Guinea	2,805	[a]	—	—
Total	2,189,595	1,780,600	56	44
Tropical America:				
Brazil	770,064	3,855,000	51	49
Mexico	197,266	159,000	45	55
Cuba	11,448	157,000	100	0
Venezuela	91,209	124,500	97	3
Colombia	113,880	95,000	100	0
Peru	128,517	84,000	39	61
Ecuador	27,067	43,000	100	0
Bolivia	109,866	25,900	23	77
Trinidad and Tobago	513	16,000	100	0
Guatemala	10,889	15,800	100	0
Jamaica	1,141	12,800	100	0
Surinam	16,382	8,500	100	0
Dominican Republic	4,838	5,700	0	100
Panama	7,709	4,000	100	0
Belize	2,297	3,100	100	0
Paraguay	40,674	3,000	63	37
Costa Rica	5,091	2,800	100	0
El Salvador	2,098	1,500	100	0
Nicaragua	13,928	1,300	100	0
Guyana	21,497	1,200	100	0
Haiti	2,775	1,000	0	100
French Guyana	9,100	450	100	0
Honduras	11,209	[a]	—	—
Total	1,584,667	4,620,550	55	45

Table A-5.—Forest Plantations in Tropical Africa, America, and Asia, 1980—Continued

Country	Total land area (1,000 ha)	Area of plantations (ha)	Industrial plantations (%)	Nonindustrial plantations (%)
Tropical Asia:				
India	328,742	2,068,000	74	26
Indonesia	191,914	1,918,000	1	99
Philippines	29,981	300,000	2	98
Viet Nam	33,433	204,000	8	92
Pakistan	80,519	160,000	0	100
Bangladesh	14,284	128,000	100	0
Thailand	68,152	114,000	55	45
Sri Lanka	6,560	112,300	100	0
Malaysia	33,068	26,000	25	75
Papau New Guinea	46,172	21,700	0	100
Nepal	14,140	18,700	74	26
Burma	67,801	16,000	3	97
Laos	23,679	11,000	70	30
Bhutan	4,662	7,000	100	0
Kampuchea	18,105	6,800	59	41
Brunei	576	a	—	—
Total	944,841	5,111,500	66	34

SOURCE: Food and Agriculture Organization/United Nations Environment Programme, *Tropical Forest Resources Assessment Project (GEMS): Tropical Africa, Tropical Asia, Tropical America*, 4 vols. (Rome: 1981).

Table A-6.—Deforestation—Tropical Africa, America, and Asia, 1981-85

Country	Annual deforestation of closed forests (1,000 ha)	Percent deforested per year
Tropical Africa:		
Ivory Coast	290	6.5
Nigeria	300	5.0
Rwanda	3	2.7
Burundi	1	2.7
Guinea-Bissau	17	2.6
Benin	1	2.6
Liberia	46	2.3
Guinea	36	1.8
Kenya	19	1.7
Angola	44	1.5
Madagascar	150	1.5
Ghana	22	1.3
Uganda	10	1.3
Zambia	40	1.3
Mozambique	10	1.3
Sierra Leone	6	0.8
Togo	2	0.7
Tanzania	10	0.7
Sudan	4	0.6
Chad	2	0.4
Cameroon	80	0.4
Zaire	182	0.2
Somalia	4	0.2
Ethiopia	8	0.2
Equatorial Guinea	3	0.2
Central African Republic	5	0.1
Congo	22	0.1
Gabon	15	0.1
Botswana	a	a
Namibia	a	a
Zimbabwe	a	a
Mali	a	a
Malawi	a	a
Upper Volta	a	a
Senegal	a	a
Niger	a	a
Gambia	a	a
Total	1,332	0.6
Tropical America:		
Paraguay	190	4
Costa Rica	65	4.0
Haiti	2	3.8
El Salvador	5	3.2
Jamaica	2	3.0
Nicaragua	121	2.7
Honduras	90	2.4
Ecuador	34	2.4
Guatemala	90	2.0
Colombia	820	1.8
Mexico	595	1.3
Panama	36	0.9
Belize	9	0.7
Dominican Republic	4.0	0.6
Brazil	1,480	0.4
Peru	270	0.4
Trinidad and Tobago	1	0.4
Venezuela	125	0.4
Bolivia	87	0.2
Cuba	2	0.1
Surinam	3	0.0
French Guiana	1	0.0
Guyana	3	0.0
Total	4,339	0.6
Tropical Asia:		
Nepal	84	4.3
Sri Lanka	58	3.5
Thailand	252	2.7
Brunei	5	1.6
Laos	100	1.2
Malaysia	255	1.2
Philippines	91	1.0
Bangladesh	8	0.9
Viet Nam	65	0.7
Indonesia	600	0.5
Pakistan	7	0.3
India	147	0.3
Kampuchea	25	0.3
Burma	105	0.3
Bhutan	2	0.1
Papua New Guinea	22	0.1
Total	1,826	0.6

[a] No data; in most cases this is where the areas are very small.

SOURCE: Food and Agriculture Organization/United Nations Environment Programme, *Tropical Forest Resources Assessment Project (GEMS): Tropical Africa, Tropical Asia, Tropical America*, 4 vols. (Rome: 1981).

Table A-7.—Per Capita Open Forest Areas in Tropical Africa, America, and Asia, 1980

Country	Open forest area (1,000 ha)	Hectares of open forest per capita
Tropical Africa:		
Botswana	32,560	40.3
Namibia	18,420	18.3
Central African Republic	32,300	14.1
Angola	50,700	7.2
Zambia	26,500	4.6
Chad	13,000	2.9
Zimbabwe	19,700	2.7
Sudan	47,000	2.6
Zaire	71,840	2.5
Guinea-Bissau	1,445	2.5
Tanzania	40,600	2.3
Senegal	10,825	1.9
Guinea	8,600	1.7
Somalia	7,510	1.6
Mozambique	14,500	1.4
Mali	8,800	1.3
Benin	3,820	1.1
Upper Volta	7,200	1.0
Cameroon	7,700	0.9
Malawi	4,085	0.7
Ethiopia	22,800	0.7
Ivory Coast	5,376	0.7
Ghana	6,975	0.6
Niger	2,900	0.5
Togo	1,380	0.5
Sierra Leone	1,315	0.4
Uganda	5,250	0.4
Madagascar	2,900	0.3
Gambia	150	0.2
Gabon	75	0.1
Kenya	1,255	0.1
Nigeria	8,800	0.1
Congo	a	b
Equatorial Guinea	a	b
Liberia	40	b
Rwanda	110	b
Burundi	14	b
Total	486,445	1.4
Tropical America:		
Paraguay	28,640	9.0
Bolivia	24,700	4.4
Surinam	690	1.8
Brazil	211,200	1.7
French Guiana	70	1.1
Belize	92	0.6
Venezuela	3,300	0.2
Colombia	5,700	0.2
Peru	1,120	0.1
Ecuador	550	0.1
Honduras	200	0.1
Costa Rica	160	0.1
Guyana	25	b
Cuba	a	b
Dominican Republic	a	b
Trinidad and Tobago	a	b
Mexico	2,100	b
Panama	a	b
Guatemala	100	b
Haiti	a	b
El Salvador	a	b
Jamaica	a	b
Nicaragua	a	b
Total	278,647	0.9
Tropical Asia:		
Laos	5,215	1.4
Papua New Guinea	3,945	1.3
Kampuchea	5,100	0.8
Thailand	6,440	0.1
India	5,393	b
Bhutan	40	b
Philippines	a	b
Bangladesh	a	b
Viet Nam	1,340	b
Indonesia	3,000	b
Pakistan	295	b
Burma	a	b
Brunei	a	b
Malaysia	a	b
Nepal	180	b
Sri Lanka	a	b
Total	30,948	b

[a] No data; in most cases this is where the areas are very small.
[b] Less than 0.05 forest hectares per capita.

SOURCE: Population Reference Bureau, *1983 World Population Data Sheet*, Washington, D.C.; Food and Agriculture Organization/United Nations Environment Programme, *Tropical Forest Resources Assessment Project (GEMS): Tropical Africa, Tropical Asia, Tropical America*, 4 vols. (Rome: 1981).

Appendix B

Glossary

Archipelago: An expanse of water with many scattered islands; a group of islands.

Agroforestry: A collective name for land-use systems and technologies where woody perennials (trees, shrubs, palms, bamboos, etc.) are deliberately used on the same land management unit as agricultural crops and/or animals, either in some form of spatial arrangement or temporal sequence. In agroforestry systems there are both ecological and economic interactions between the different components.

Alluvial soils: Soils made of materials deposited by running water (e.g., clay, silt, sand, and gravel).

Aquifer: A water-bearing stratum of permeable rock, sand, or gravel.

Atoll: A coral island consisting of a reef surrounding a lagoon.

Biological diversity: Includes two related concepts, genetic diversity and ecological diversity. Genetic diversity is the amount of genetic variability among individuals in a single species, whether the species exist as a single interbreeding group or as a number of populations, strains, breeds, races, or subspecies. Ecological diversity (species richness) is the number of species in a community of organisms. Both kinds of diversity are fundamental to the functioning of ecological systems.

Biome: A major ecological community type (e.g., grassland); a major biotic unit consisting of plant and animal communities having similarities in form and environmental conditions.

Biotic: Of or relating to life; caused or produced by living things.

Broadleaf forest: A type of closed forest where broadleaf species (dicotyledons or monocotyledons) predominate. The broadleaf trees (especially the dicotyledons) are often referred to as "hardwoods."

Canopy: The more or less continuous cover of branches and foliage formed collectively by the crowns of adjacent trees and other woody vegetation. Layers (i.e., understory and overstory) of the canopy may be distinguished.

Clearcutting: The removal of the entire standing crop of trees. In practice, may refer to exploitation that leaves much unsaleable material standing (e.g., a commercial clearcutting).

Closed forest: Includes land where trees shade so much of the ground that a continuous layer of grass cannot grow. The tree cover is often multistoried. Trees may be evergreen, semideciduous, or deciduous. Closed forests grow where the climate is relatively moist. Also called moist forest.

Cloud forests: Forests where clouds impinge almost continuously on tropical mountain vegetation. Generally a dense growth of trees of various diameters draped with mosses, ferns, and leafy liverworts.

Coir-fiber: A stiff, coarse fiber from the outerhusk of coconut.

Commonwealth: In the context of American territorial relations, the status currently held by Puerto Rico and approved for the Northern Mariana Islands. Denotes a high degree of local autonomy under a constitution drafted and adopted by the local residents.

Conifer: Any of an order (*Coniferales*) of mostly evergreen trees and shrubs including forms (as pines) with true cones and others (as yews) with an arillate fruit. Most are needle-leaved trees. Often referred to as *softwoods*.

Conifer forest: A type of closed forest. It includes only areas where conifer species (gymnosperms) predominate. These trees are often referred to as "softwoods."

Conservation: The management of human use of the biosphere so that it benefits present generations while maintaining its potential to meet the needs of future generations.

Converted land: Includes any land that has changed from a natural to a manipulated state, such as cropland planted annually or every few years with food or fiber crops and rangeland covered permanently with grasses, legumes, and/or herbaceous species and harvested by grazing livestock.

Coppice: A forest of trees that has grown from shoots or root suckers rather than seed. Coppicing refers to cutting trees close to ground level so they will regrow from coppice shoots.

Copra: Dried coconut meat yielding coconut oil.

Deciduous: Of perennial plants that are normally leafless for some period during the year.

Deforestation: The conversion of forests to land uses that have a tree cover of less than 10 percent.

Degradation: Refers to the biological, physical, and chemical processes that result in the loss of the productive potential of natural resources—e.g., soil erosion and loss of valuable or potentially valuable genetic types.

Dendrothermal: Caused by or relating to heat generated by burning wood.

Desertification: A process of extreme degradation of the biological potential of the land that can lead ultimately to desert-like conditions.

Dipterocarp forests: Forests dominated by trees of the Dipterocarpaceae family. These are tall trees of tropical Asia, Indonesia, and the Philippines that have a two-winged fruit and are the source of valuable timber, aromatic oils, and resins.

Disturbed forest: Forest that has been cleared in large areas within the last 60 years, commonly for crops or pasture. Usually it is sufficiently degraded or harvested regularly so it does not return to its original state. Trees may be managed or left to natural successions. The term includes *plantations*.

Dry forest: See *open forest*.

Ecological diversity: See *biological diversity*.

Ecosystem: A unit of plant and animal life, within its nonliving environment, the components of which are linked together by a variety of processes, including the flow of energy through the system and the cycling of nutrients within it.

Endangered species: Species threatened with extinction as listed in the Endangered Species Act of 1973 and subsequent amendments.

Endemic: Restricted or peculiar to a locality or region. Native.

Eutrophic: Rich in dissolved nutrients (as phosphates). Often shallow and seasonally deficient in oxygen.

Environmental services: Benefits provided by the environment or environmental processes, often with values difficult to quantify. Examples include the erosion control function of vegetation and the filtering function of mangrove forests.

Exotic: Introduced from another country; not native to the place where found.

Free association: Proposed status for the peoples of Palau, the Marshall Islands, and the Federated States of Micronesia—currently the Trust Territory of the Pacific Islands. Provides for full internal self-government and substantial authority in foreign affairs. The United States would have responsibility for defense and some specified economic assistance.

Forest fallow: Land that has been cleared of its trees for cultivation and subsequently abandoned so that it may again have some woody vegetation. This includes patches of land that are being used to grow crops and some patches where forest has not been cleared which are too small to account for separately. The category does not include land where erosion or leaching have so degraded the site that only shrubs or grasses grow after the land is abandoned.

Forest resources: Includes trees, the organisms associated with them, and the land, waters, and microclimates that are substantially affected by them.

Forest structure: Distribution and arrangement of trees in a forest.

Fuelwood: Wood used as fuel for purposes of cooking, heat, or power production. Wood for charcoal, kilns, and ovens is included.

Genetic diversity: See *biological diversity*.

Geomorphology: Science that deals with the land and submarine relief features of the Earth's surface; the features dealt within geomorphology.

Germ plasm: Germ cells and their precursors serving as the bearers of heredity and being fundamentally independent of other cells; the hereditary material of the germ cells. Genes.

Hardwood: A conventional term for the timber of broadleaved trees, and the trees themselves, belonging to the botanical group Angiospermae.

Hectare: One hectare equals 2.47 acres. One square kilometer equals 100 hectares. One square mile equals 259 hectares. Thus, the 1.2 billion hectares of closed tropical forest is equal to 3 billion acres or 4.6 million square miles.

Horticulture: The science and art of growing fruits, vegetables, flowers, or ornamental plants.

Hydrology: The study of the circulation of water in and between the atmosphere and the Earth's crust, with particular emphasis on the phases initiated by precipitation and ending with evapotranspiration. Water cycle.

Hyphae: The threads that make up the mycelium of a fungus.

Indigenous: Native to a specified area or region, not introduced. Endemic.

Industrial plantations: Sites where trees are planted to produce sawlogs, veneer logs, pulpwood, and pitprops. The category excludes plantations that produce fuelwood for industrial use.

Industrial wood: Wood used for sawlogs, veneer logs, pit props, pulpwood, chips, particles, or other construction purposes. Does not include fuelwood.

In situ: Protecting stock in the original habitat rather than in cold storage or in places such as gene banks and botanical or zoological gardens.

Insular: Of, relating to, or constituting an island; dwelling or situated on an island.

Laterite: A red residual product of rock decay that has a high content of oxides of iron and hydroxide of aluminum.

Landsat: Originally called Earth Resources Technological Satellite (ERTS). A group of satellites using electromagnetic sensors to record reflected radiation from the Earth to provide imagery to depict ground cover, etc. Remote-sensing tool important for resource inventories.

Leeward: Being in or facing the direction toward which the wind is blowing; the side opposite the windward.

Legally protected forest: Forests where logging is prohibited by law. It includes a variety of types of parks and protected areas. Illegal logging and agricultural clearing does occur in some of these areas.

Legumes: Any of a large family (Leguminosae) of dicotyledonous herbs, shrubs, and trees bearing nodules on the roots that contain nitrogen-fixing bacteria, and including important food, forage, and timber plants (as peas, beans, carob, or rosewood.)

Littoral: Of, relating to, or situated or growing on or near a shore, especially of the sea.

Logged-over forest: Productive forest area that has been logged or cleared at least once in the last 60 years but does not fit the criteria for managed forest. This category is not applied to open forests.

Managed forest: Productive forest where harvesting regulations are enforced, silvicultural treatments are carried out, and trees are protected from fires and diseases.

Mangroves: Any of a genus (*Rhizophora,* especially *R. mangle*) of tropical maritime trees or shrubs that throw out many prop roots and form dense masses important in coastal areas.

Manmade forest: See *plantations.*

Marginal land: Land that is relatively infertile or unproductive for agriculture without extraordinary capital imputs (as irrigation, fertilizer).

Merchantable: Of commercially acceptable quality. Salable.

Moist forest: See *closed forest.*

Monoculture: One species planted over a large area.

Montane: Of, relating to, growing in, or being the biogeographic zone that is made up of relatively moist cool upland slopes below timberline and that is characterized by large evergreen trees as a dominant life form.

Mycorrhiza: The symbiotic association of the mycelium of a fungus with the roots of a seed plant.

New world: North, South, and Central America.

Open forests: Trees cover at least 10 percent of the ground but still allow enough light to reach the forest floor so that a continuous cover of grass can grow. Generally occur where the climate is relatively dry.

Open woodlands: See *open forests.*

Palmito: Any of several usually low-growing fan-leaved palms. Strips of the leaf blade of a palmetto used in weaving.

Phenology: A branch of science dealing with the relations between climate and periodic biological phenomena (as bird migration or plant flowering).

Phenotype: Any organism as observed—i.e., as judged by its visually perceptible characters resulting from the interaction of its genetic characteristics with the environment.

Pioneer species: A plant capable of invading bare or newly exposed sites and persisting there—i.e., colonizing them—until supplanted by succession species.

Plantation: A forest crop or stand established artificially either by sowing or planting. The term includes reforestation (reestablishment of a tree cover on deforested or degraded forest lands) and replacement of natural forest by a different tree crop. It does not include artificial regeneration (the application of postharvesting techniques to accelerate the regrowth of the species that had been logged).

Possession: Used to refer to any unincorporated territory of the United States—i.e., any territory to which the Constitution has not been expressly and fully extended. Includes American Samoa, Guam, and the Virgin Islands.

Productive forest: The characteristics of the trees, terrain, and forest regulations potentially allow the production of wood for industrial purposes (e.g., sawlogs, veneer logs, pulpwood, and industrial poles). Relates to both closed and open forests. The distance to consumption or export centers is not taken into account, so the category includes some forests that are not now economically accessible.

Propagule: A structure (as a cutting, a seed, or a spore) that propagates a plant.

Provenance trials (or tests): Testing populations of the same species to study their performance under a range of site and climatic conditions. In a provenance test, seeds are collected from a number of widely scattered stands and the seedlings are grown under similar conditions.

Race: Subdivision of a species distinguished by heritable physiological or morphological characteristics resulting from adaptation to a specific environmental condition. Tree species races are often described by referring to the geographic location where the race is found naturally.

Rhizomes: Underground, root-like stem of plant.

Roundwood: Wood in the natural state as felled, or otherwise harvested, with or without bark, round, split, or squared. It comprises all wood obtained from removals. Commodities included are sawlogs, veneer logs, pit props, pulpwood, other industrial roundwood, and fuelwood.

Secondary forests: Forest growth that has come up naturally after some major interference (e.g., logging, serious fire, or insect attack).

Selectively cut: The removal of only the most valuable trees.

Shrubland: Land that has woody vegetation covering at least 10 percent of the ground, but the main woody plants are bushy species with a height at maturity of 0.5 to 7 meters. Shrubland may be the natural vegetation under dry or otherwise stressful conditions, or it may result from severe degradation of open or closed forest.

Shifting cultivation (also called slash-and-burn agriculture): Any farming system where land is periodically cleared, cropped, and returned to fallow.

Siltation: To choke, fill over, or obstruct with silt or mud.

Silviculture: The science and art of cultivating forest crops, based on a knowledge of forest tree characteristics.

Social and environmental plantations: Plantations designed for soil and water protection or to produce fuelwood and charcoal, polewood, or construction wood for local use, or some nonwood products such as gum arabics. The category excludes plantations for major nonwood commodities such as rubber, palm oil, coconuts, cloves, coffee, and cocoa. It also excludes trees planted to shade agricultural crops.

Softwood: A conventional term for both the timber and the trees belonging to the botanical group Gymnospermae. Commercial timbers of this group are generally confined to conifers.

Sustain (sustaining, sustainable): To maintain or increase the productivity and renewability of the resources in perpetuity.

Symbiosis: The intimate living together of two dissimilar organisms in a mutually beneficial relationship.

Taungya: Burmese word for hill cultivation. The principal objective is to plant crops of trees used for wood production. People are allowed to grow food crops among the newly planted trees for one or a few years.

Tissue culture: Microbiological technique for asexual reproduction of plants in vitro from a selected parent.

Tree: A woody perennial plant having a single, usually elongate, main stem generally with few or no branches on its lower part.

Trust territory: Areas placed under the international trusteeship system of the United Nations, territories detached from enemy states as a result of World War II, and territories voluntarily placed under the system. Are administered pursuant to the terms of individual agreements.

Tropics: The region lying between the Tropic of Cancer and the Tropic of Capricorn, 23.5° North and 23.5° South of the Equator. In this report, tropical forest includes all forest of the 76 listed nations, whether or not they are actually in the Tropics.

Undisturbed forest: Productive forest that has not been logged or cleared in the last 60 years, including both primary forest and old secondary forest. Natural tropical forest with at most a few small areas cleared by natural or human-induced events, regenerating by natural stages of succession. The term is not applied to open forests because nearly all open forests have been subject to cutting, burning, and grazing.

Unproductive forest (for physical reasons): Forest unsuitable for industrial wood production because of rough or inundated terrain or poor growth characteristics of the trees (stunted or crooked).

Unproductive land: Land that has been so degraded that it produces few useful products and provides minimal environmental services. It usually supports very little growth of useful species and does not return naturally to other categories of land.

Watershed: A region or area draining ultimately to a particular watercourse or body of water.

Weeding: Eliminating or suppressing undesirable vegetation so as to reduce competition with desirable vegetation.

Appendix C

Commissioned Papers

Technologies to Increase Production From Primary Tropical Forests and Woodlands

Peter S. Ashton
Harvard Arnold Arboretum

Mark J. Plotkin
Harvard Botanical Museum

Methods for Evaluating Tropical Forest and Woodland Plants to Indicate Their Potential as Resources

Michael J. Balick
New York Botanical Garden

Tree Crops: Key Elements in Sustaining Tropical Forest Resources

Earle Barnhart
The New Alchemy Institute

Professional Education and Technical Training to Support Development and Implementation of Technologies to Sustain Tropical Resources

James S. Bethel and David B. Thorud
College of Forestry
University of Washington

William Burch
School of Forestry
Yale University

Applied Research in the United States Relevant to Tropical Forests and Woodlands

David H. Dawson
Forestry Sciences Laboratory

Causes of Deforestation and Forest and Woodland Degradation in Tropical Latin America

William M. Denevan
Department of Geography
University of Wisconsin-Madison

Technologies for Reforestation of Degraded Lands in the Tropics

Carl M. Gallegos
U.S. Agency for International Development

Charles B. Davey, Robert L. Kellison,
Pedro A. Sanchez, and Bruce J. Zobel
Department of Forestry
North Carolina State University

Afforestation and Management of Tropical Wastelands in India

R. C. Ghosh
Additional Chief Conservator of Forests
West Bengal, India

Causes of Deforestation in Tropical Asia

Christopher Gibbs
British Columbia Ministry of Environment

The Use of Traditional Knowledge in Development and Implementation of Resource-Use Systems That Sustain Tropical Forest and Woodland Resources

Stephen R. Gliessman
College of Environmental Studies
University of California-Santa Cruz

Valuing Goods and Services From Tropical Forests and Woodlands

Hans M. Gregersen
Department of Forestry
University of Minnesota-St. Paul

Deforestation and Environmental Change in the West African Sahel

Jeffrey Allman Gritzner
Board on Science and Technology for
International Development
National Academy of Sciences

Land-Use Planning Technologies to Sustain Tropical Forest and Woodlands

Lawrence S. Hamilton
East-West Center

Technologies to Improve the Use of Tropical Forest and Woodland Products

Joseph Frederick Hughes,
Robert Aubrey Plumptre, and Jeffery Burley
Commonwealth Forestry Institute
England

The Relationship of Basic Research to the Development of the Technologies That Will Sustain Tropical Forest Resources

Daniel H. Janzen
Department of Biology
University of Pennsylvania-Philadelphia

Identification and Development of New Tropical Forest Resources in Puerto Rico and the U.S. Virgin Islands

Connie Krochmal
Economic Botanist
Agriculture and Science Associates

The Use of Agroforestry to Improve the Productivity to Converted Tropical Land

Bjorn Lundgren
International Council for Research
in Agroforestry

Professional Education and Technical Training to Support Development and Implementation of Technologies to Sustain Tropical Resources

Hank Margolis
Oregon State University

Methods for the Establishment and Management of Protected Areas for Tropical Primary Forest and Woodland Resources

Kenton R. Miller and Dennis Glick
School of Natural Resources
University of Michigan-Ann Arbor

The Importance of Tropical Forests and Woodland Resources

Norman Myers
Consultant in Environment and Development

Soil and Water Management Technologies for Tropical Forests

Charles Pereira
Consultant in Tropical Agricultural Research
and Land-Use Hydrology
England

Social Forestry in India: An Analytical Framework for Evaluation of Its Problems and Prospects

Christopher Prins
University of California-Berkeley

Basic Research—A Necessary Prerequisite for Adequate Development of Technologies to Sustain Tropical Forest Resources

Peter H. Raven
Missouri Botanical Garden

Institutions That Deal With Technologies to Sustain Tropical Forest Resources

Bruce Rich
Natural Resources Defense Council

Private Foundations That Support Projects Relating to Technologies to Sustain Tropical Forest Resources

Bruce M. Rich
Natural Resources Defense Council

Causes of Deforestation and Forest and Woodland Degradation in Tropical Africa

James C. Riddell
Land Tenure Center
University of Wisconsin-Madison

Dynamics of Tropical Forest Conversion: A Preliminary System Dynamics Model

Jennifer Robinson
Department of Geography
University of California-Santa Cruz

Forestry: Puerto Rico and the Virgin Islands

Ralph Schmidt
Forest Service
Department of Natural Resources
Puerto Rico

Fuelwood Technologies to Sustain Tropical Forest Resources

Asif M. Shaikh and Samuel Hale, Jr.
Energy Development International

Tahir Qadri
CARE

Opportunities and Constraints for Improving the Use of Tropical Mangrove Forests

Howard J. Teas
Department of Biology
University of Miami-Coral Gables

Common-Property Resources and Individual Ownership

Denise M. Toombs
Resource Policy Center
Dartmouth College

Sustaining Tropical Forest and Woodland Animal Resources

Noel D. Vietmeyer
Board on Science and Technology for International Development
National Academy of Sciences

Secondary Forest Management and Plantation Forestry Technologies to Improve the Use of Converted Tropical Lands

Frank H. Wadsworth
Institute of Tropical Forestry
Puerto Rico

Environmental Education Technologies as Applied to Tropical Forest Management

Diane Walton
International Institute for Environment and Development

David Wood
National Wildlife Federation

Combatting Desertification With Trees

Fred R. Weber
International Resources Development and Conservation Services

Halting Tropical Deforestation: The Role of Technology

Jack Westoby
Consultant in Forest Economics
Italy

Congressional Action to Improve the Sustainability of U.S. Tropical Forest Resources in the Pacific

Craig D. Whitesell, Charles W. Philpot, and Marjory C. Falanruw
Pacific Southwest Forest and Range Experiment Station
U.S. Department of Agriculture Forest Service

Technologies and Technology Systems for Reforestation of Degraded Tropical Lands

P. J. Wood, J. Burley, and A. Grainger
Commonwealth Forestry Institute
England

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